

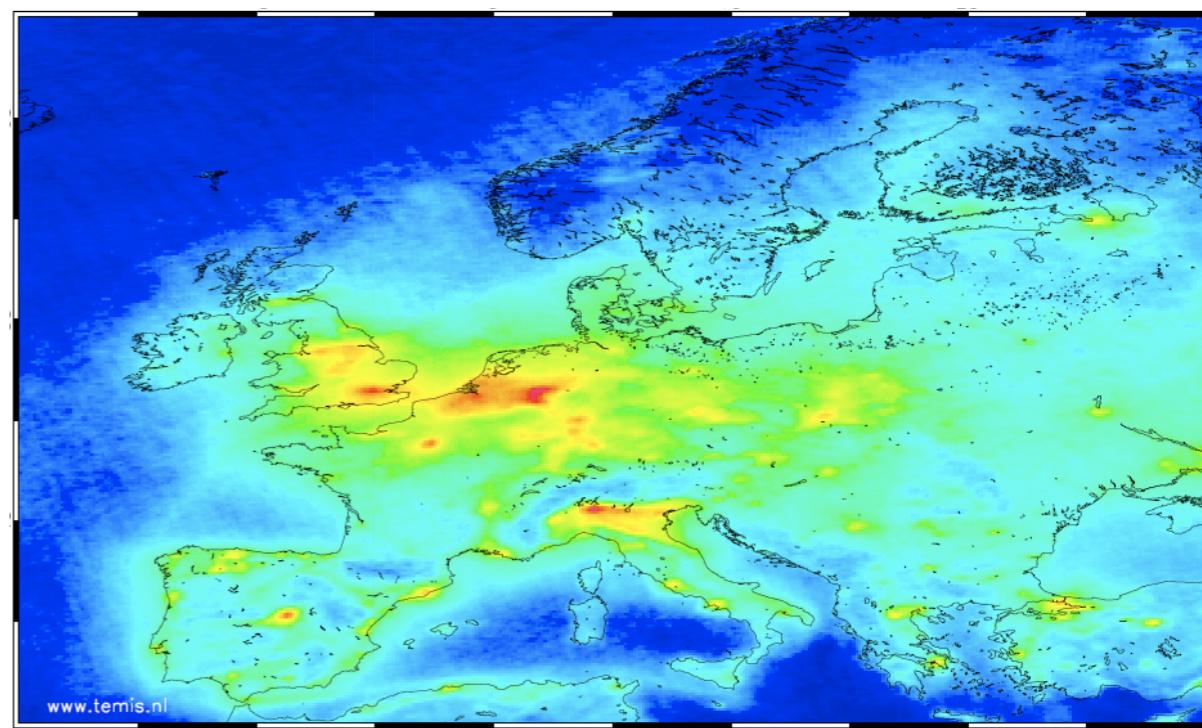


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Estimating NO_x emissions and trends by combining measurements, air quality models and Ensemble Kalman Filter data assimilation

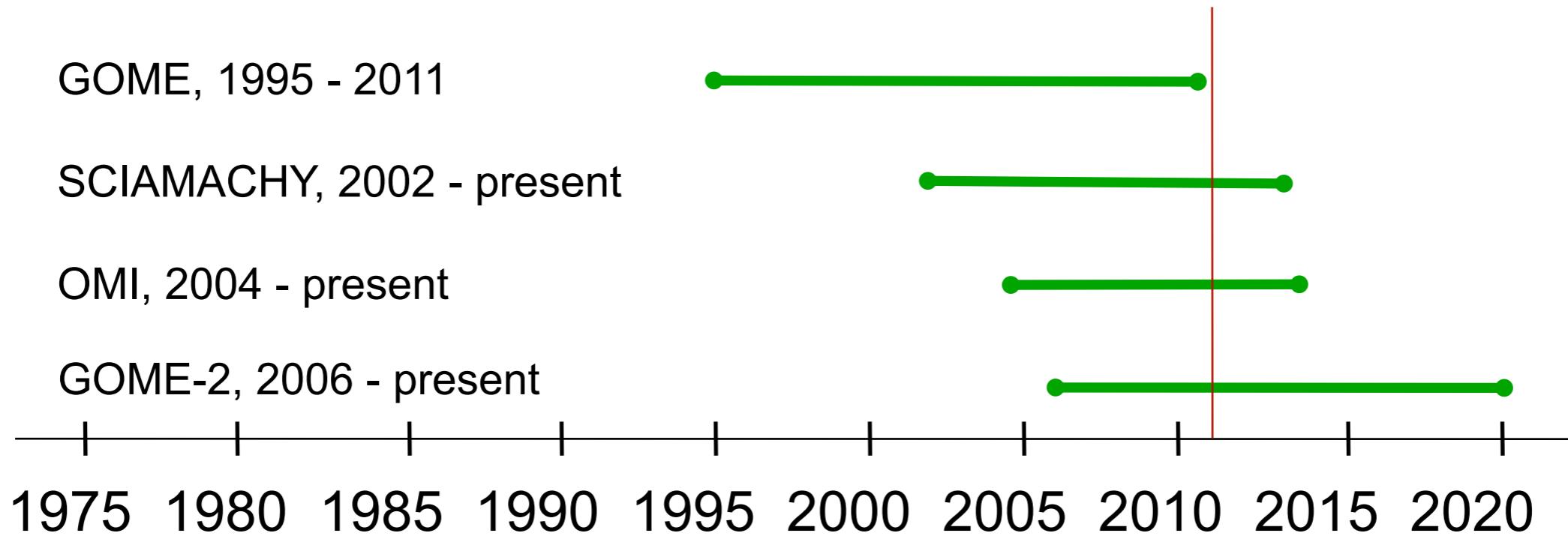
**Henk Eskes,
Martijn de Ruijter, Tim Vlemmix, Ronald vd A (KNMI, the Netherlands)
Lyana Curier, Renske Timmermans, Arjo Segers (TNO, the Netherlands)
Ferd Sauter (RIVM, the Netherlands)**

MACC project

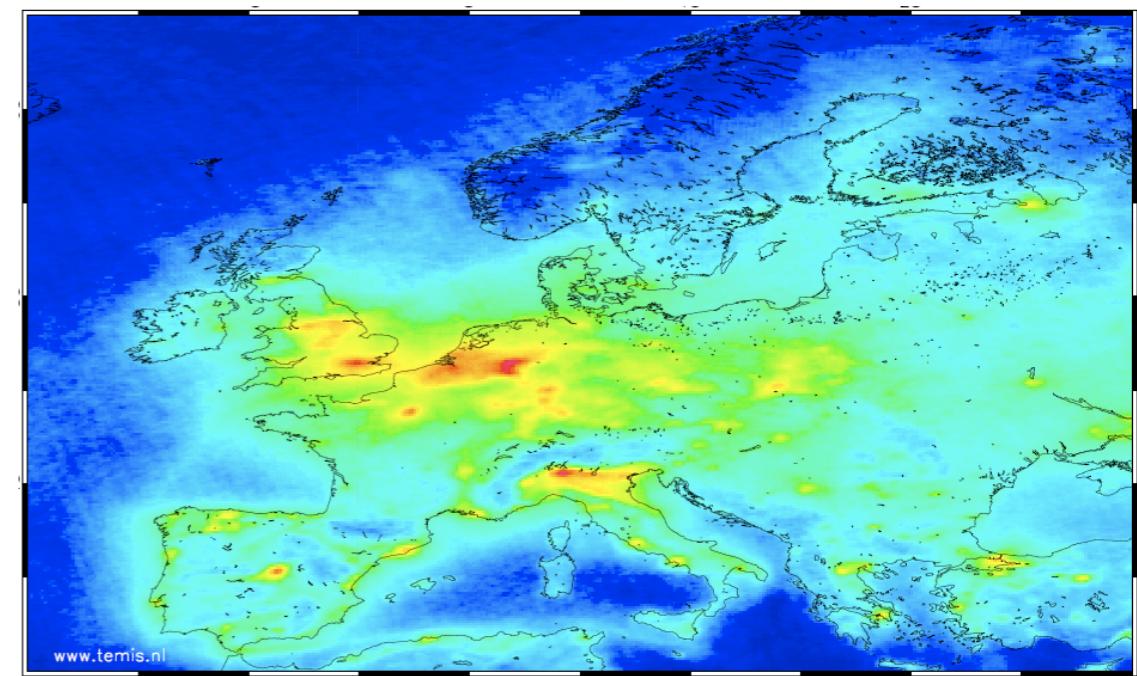




Satellite NO₂ measurements, 1995-2011

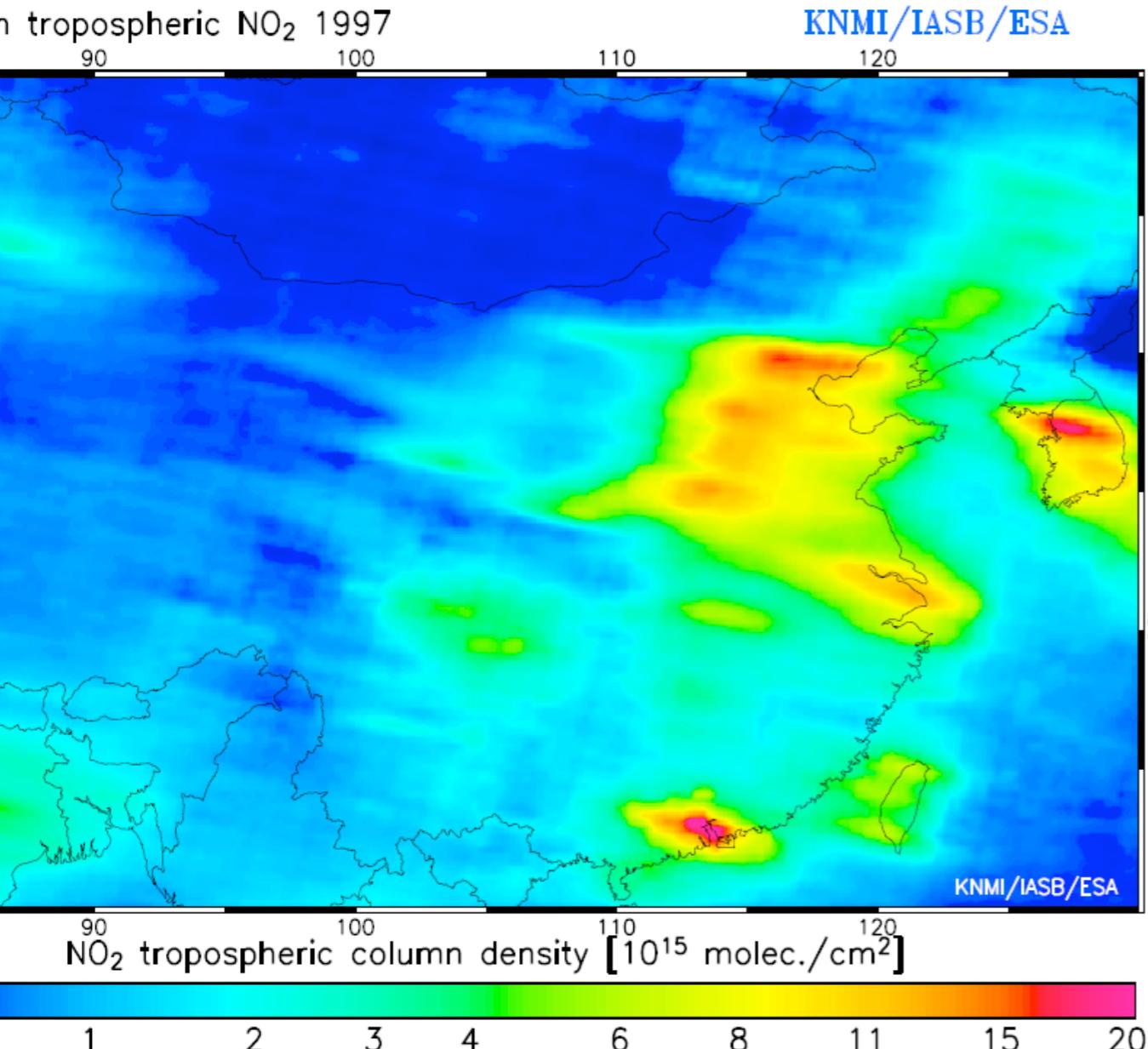


Resolution 300 km → 20 km → 8 km (TROPOMI)

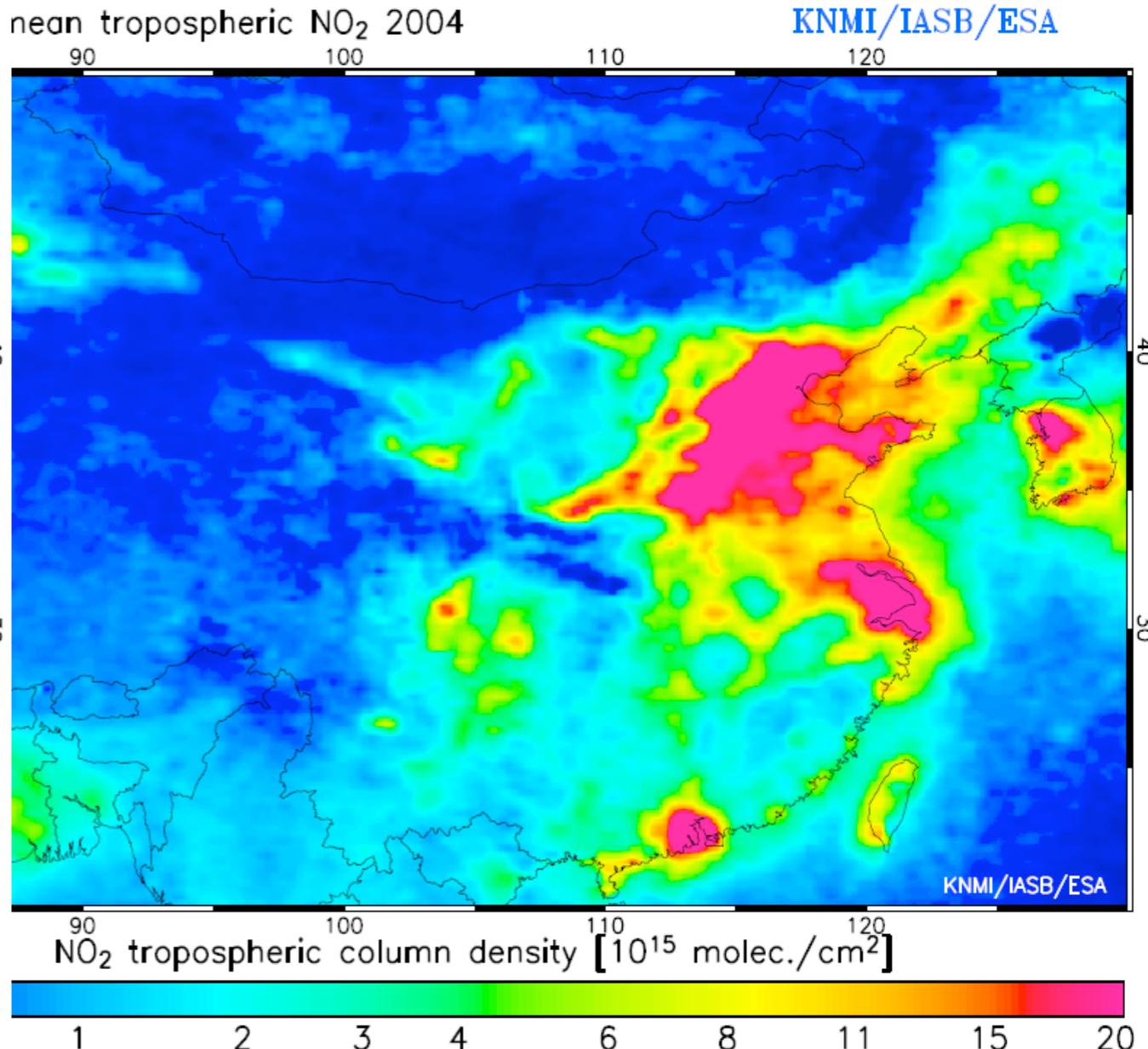


Trend in NO₂ over China

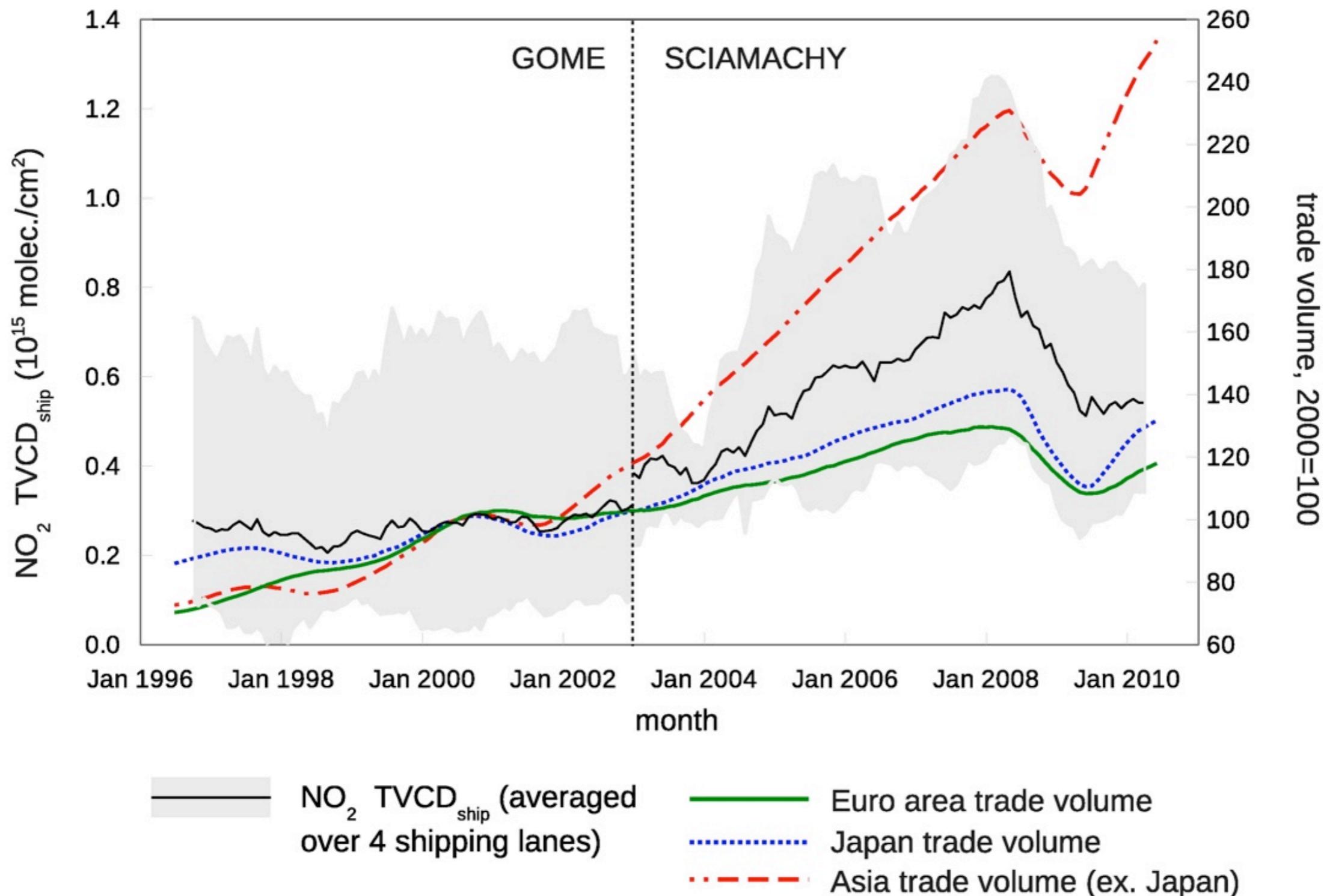
GOME, 1997



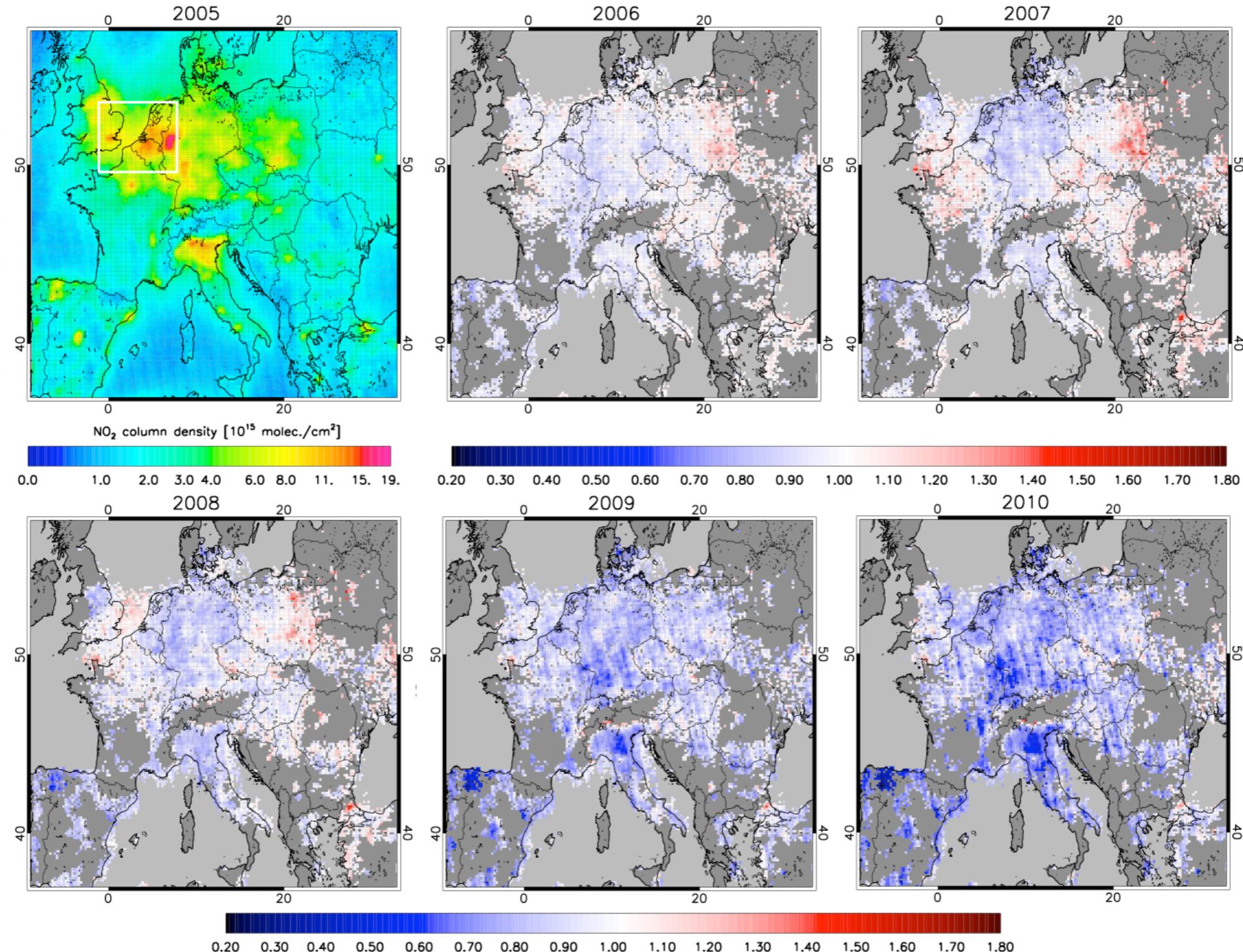
SCIAMACHY, 2004



Trend in NO₂ from shipping, vs trade

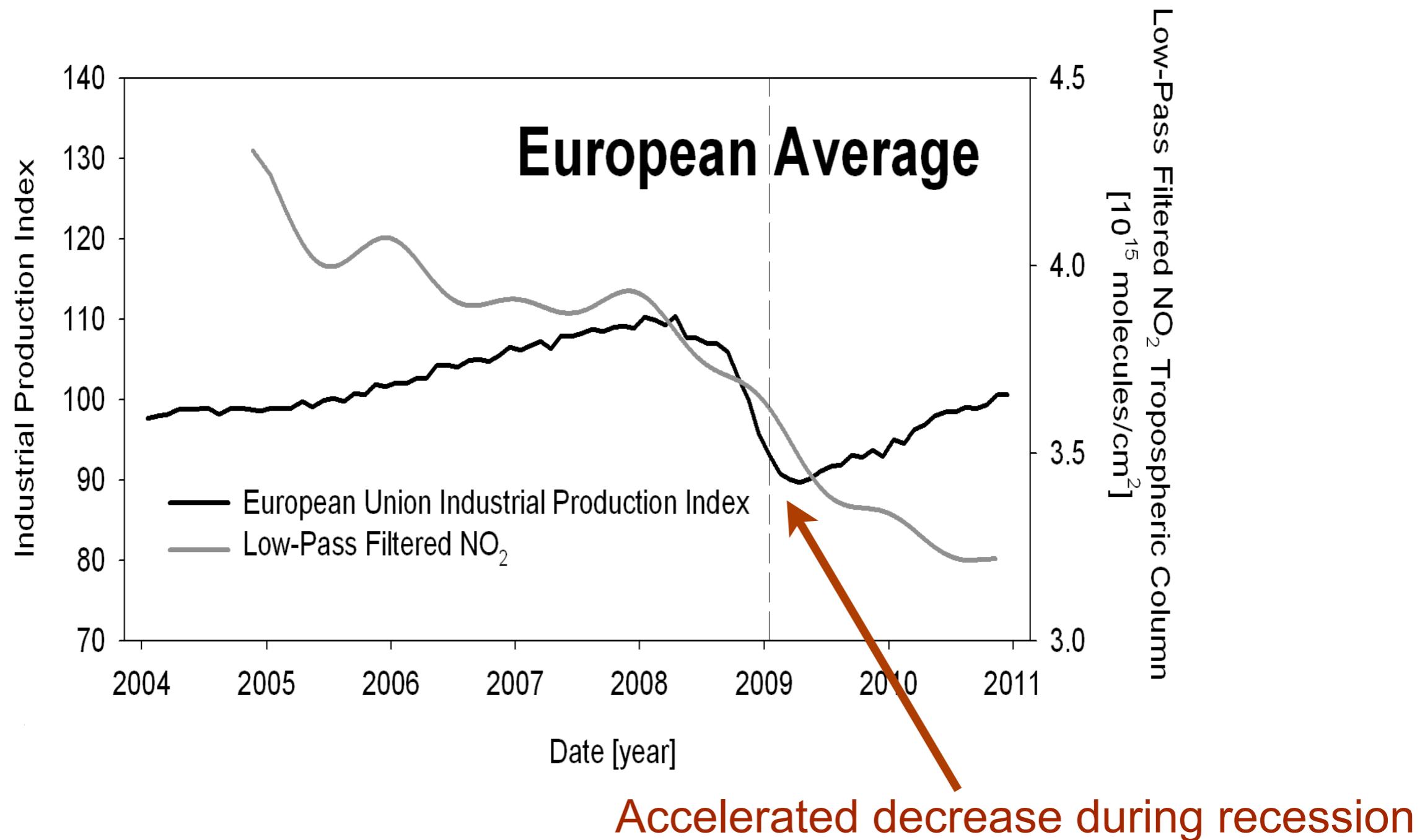


European trend in NO₂ from OMI (August)



Castellanos and Boersma, submitted

European trend in NO₂ vs. Economy





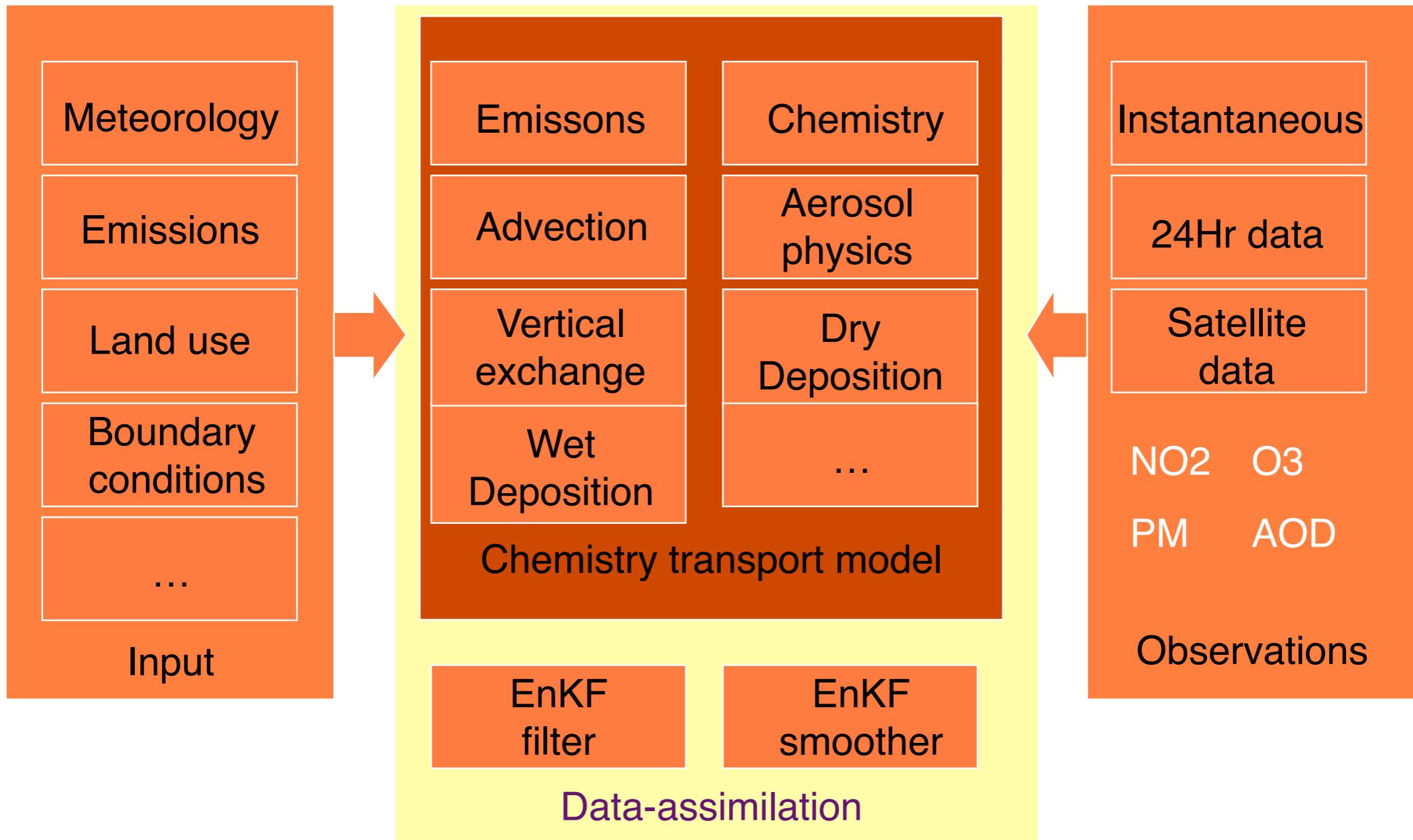
Estimating European NOx emissions by combining OMI NO2 observations, the Lotos-Euros air quality model and data assimilation

A number of sensitivity studies

Dutch Lotos-Euros air quality model



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- ECMWF meteo
- Dynamic BL scheme (4 layer model)
- top at 3.5 km

- Operational forecasts NL
- Contribute to MACC ensemble

Comparison LotosEuros and MaxDOAS



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MaxDOAS instrument KNMI

- November 2007 - April 2009
- 355 days of observations
- Multiple obs per day (1h averages)
- On roof KNMI, looking North-East
- Based 30 deg elevation measurement (divided by zenith)
- Use made of Ceilometer data (cloud cover)

LOTOS-EUROS

- v1.7.001 (2011)
- High resolution runs, 7km
- Emissions (TNO-MACC) available on same resolution
- Runs for periods when MaxDOAS is in operation

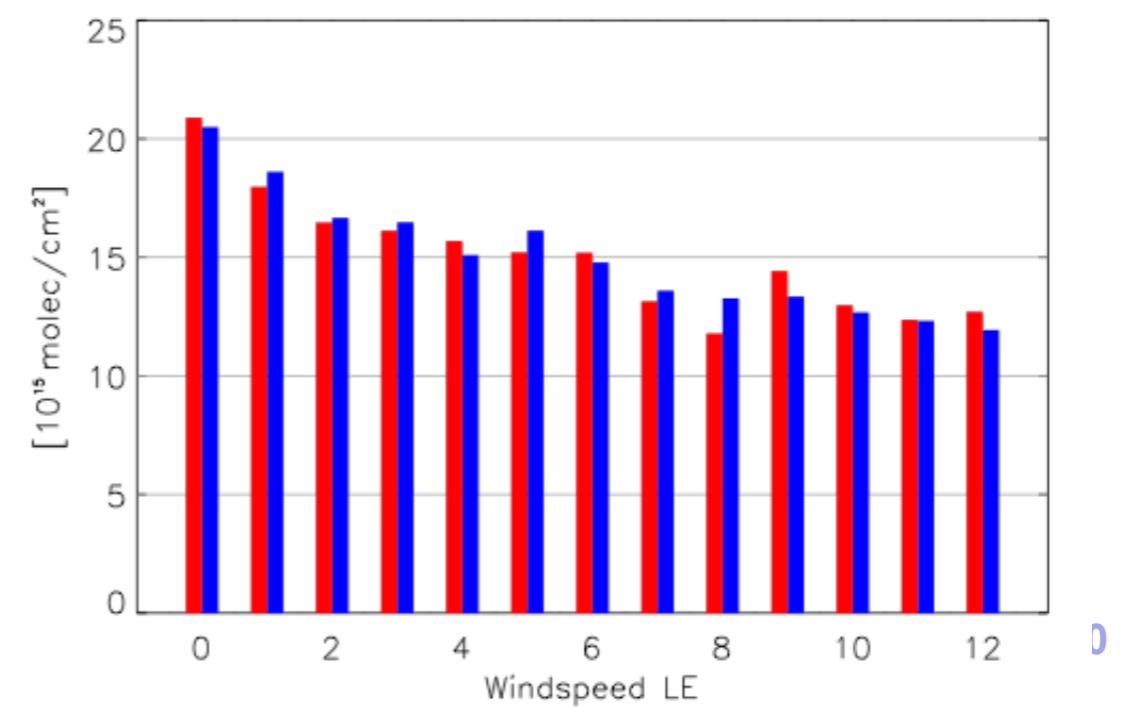
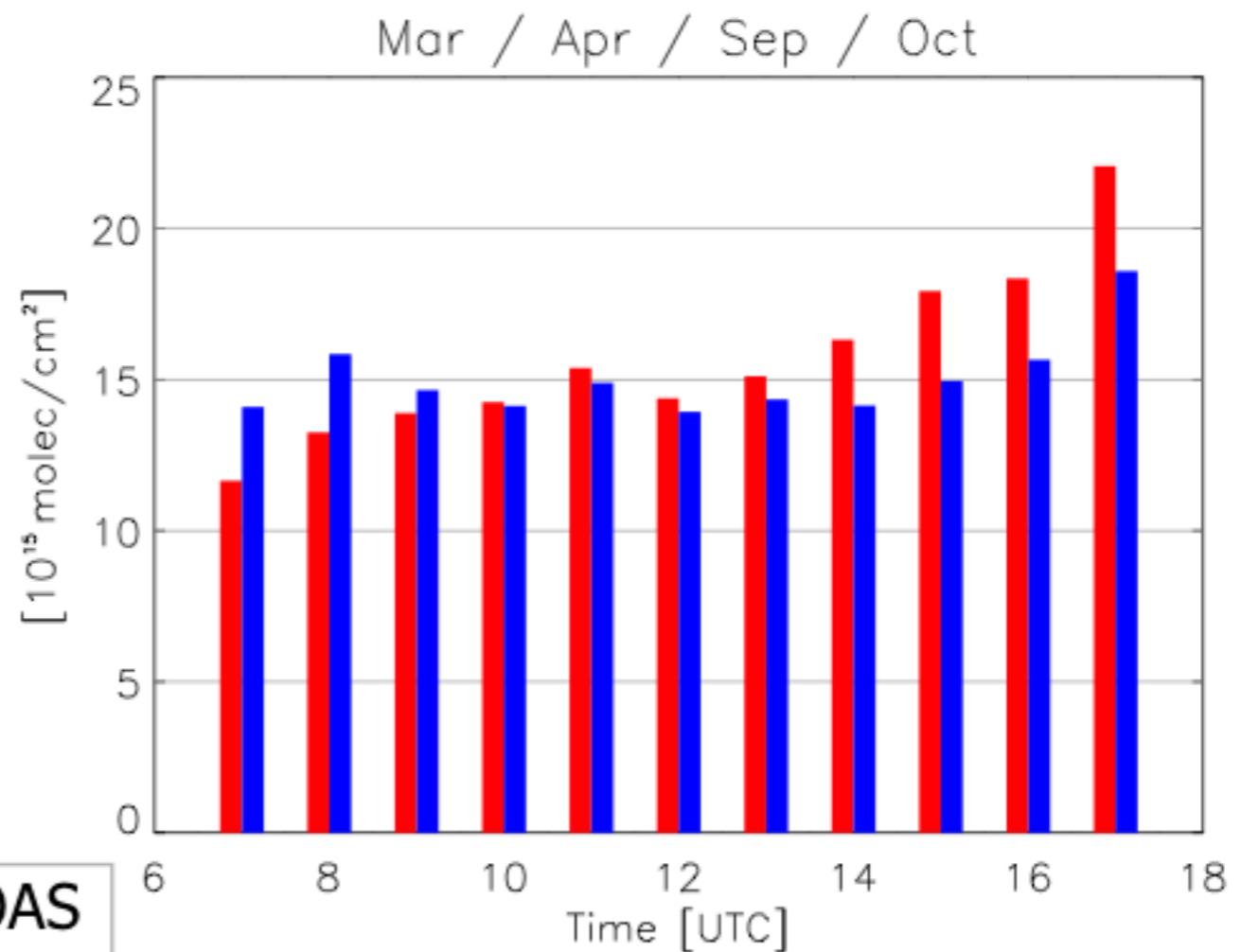
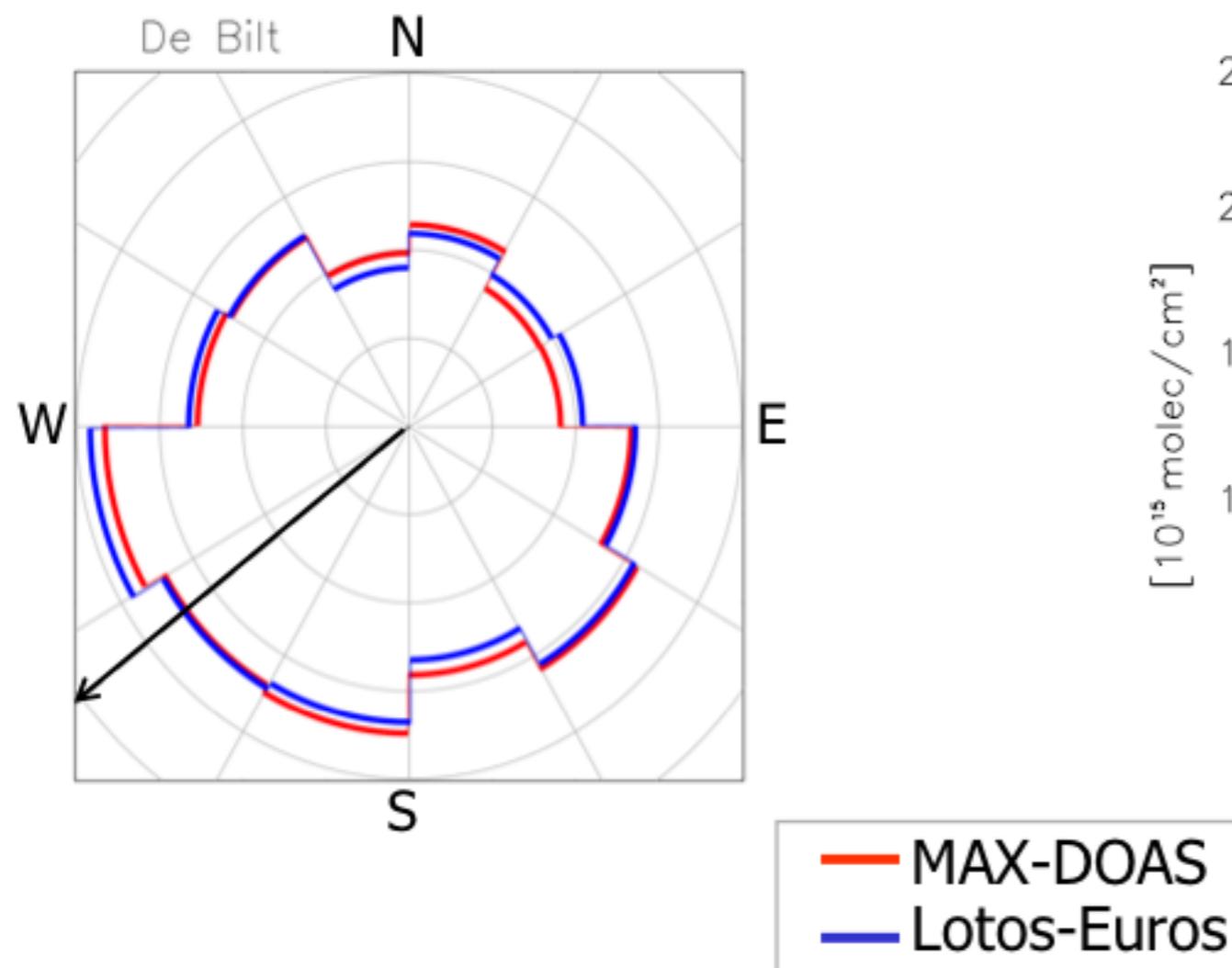
Tim Vlemmix et al., submitted



Comparison LotosEuros and MaxDOAS



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Data assimilation with Lotos-Euros

OMI NO₂ measurements

- Three products: DOMINO 1 & 2, EOMINO (EMPA)
- Use averaging kernels and error estimates

Lotos-Euros

- European (MACC) domain, 30 km resolution
- Use TM5 simulations to describe free troposphere.

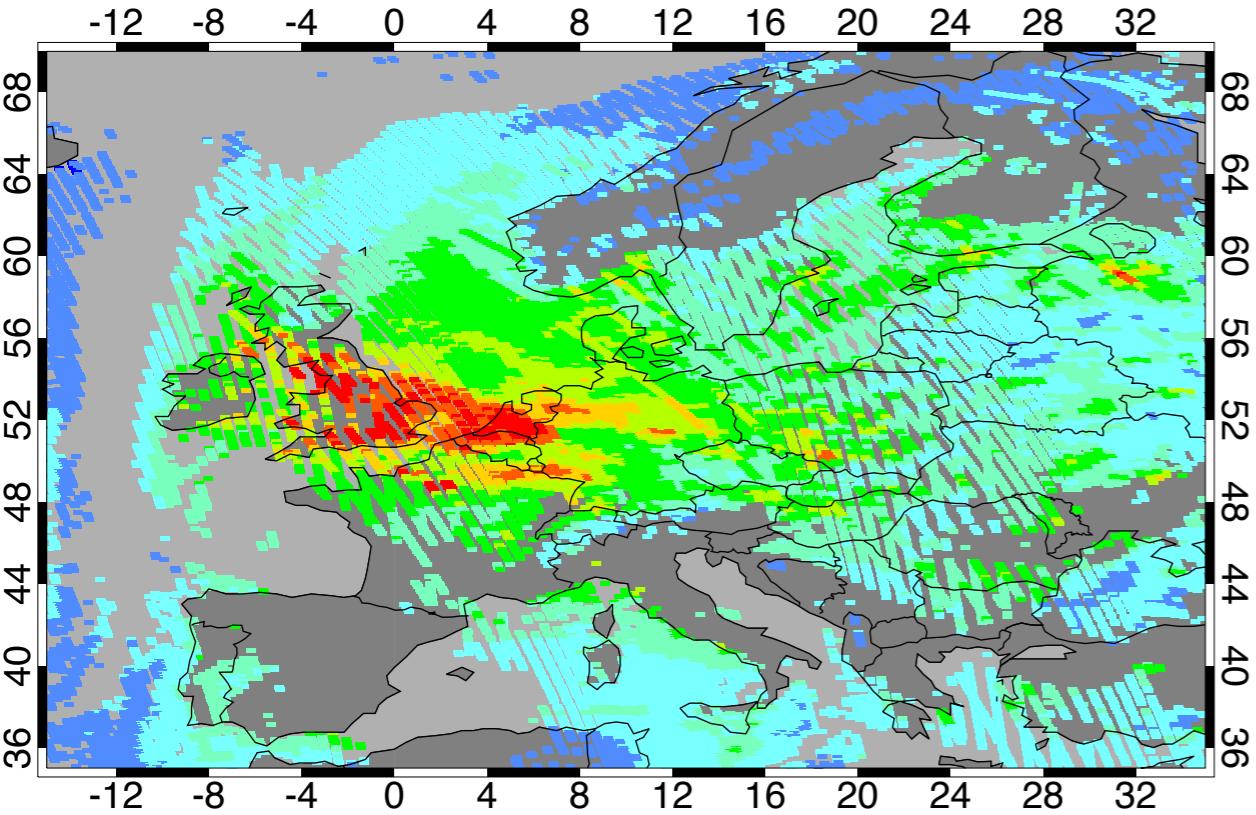
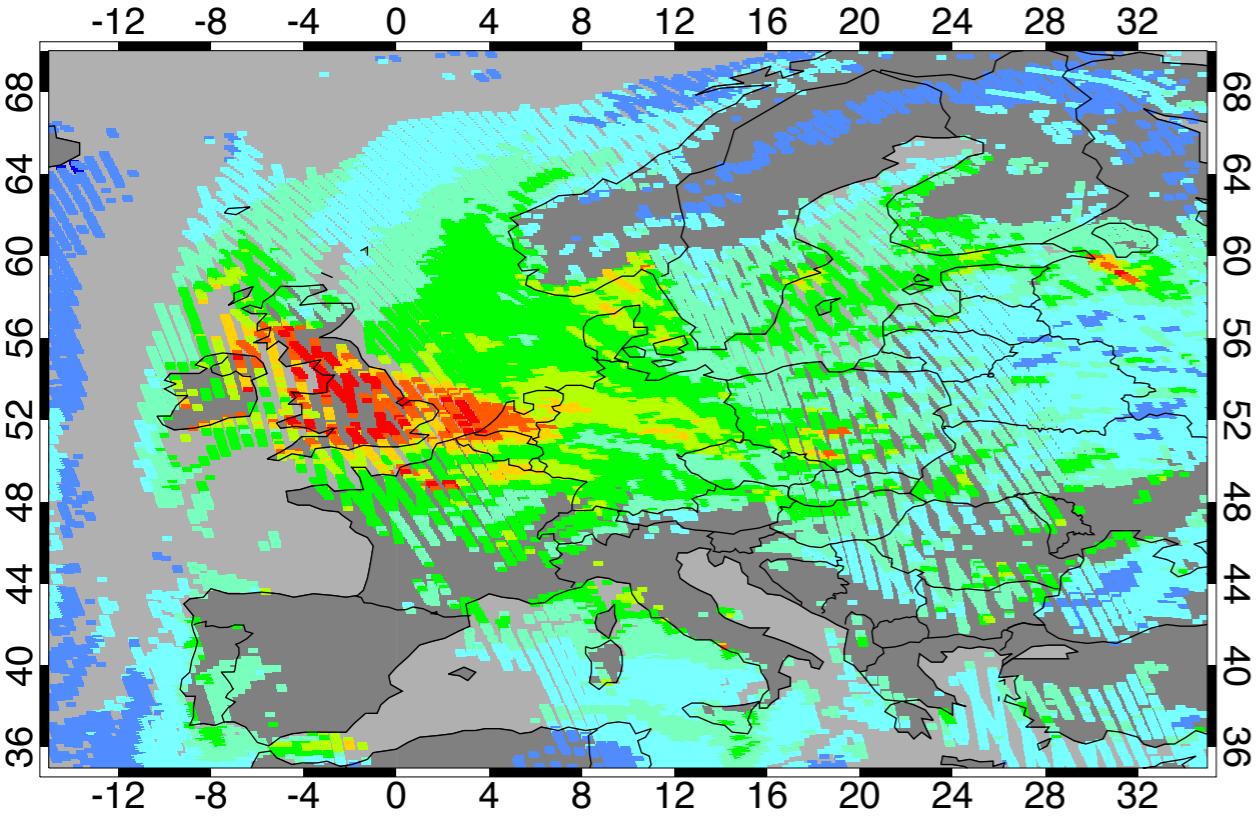
Ensemble Kalman filter technique

- Updating NO_x emissions
optionally also VOC emissions, boundary conditions, deposition
- 5 week assimilation runs

Assimilation DOMINO v2 - 27 march 2007



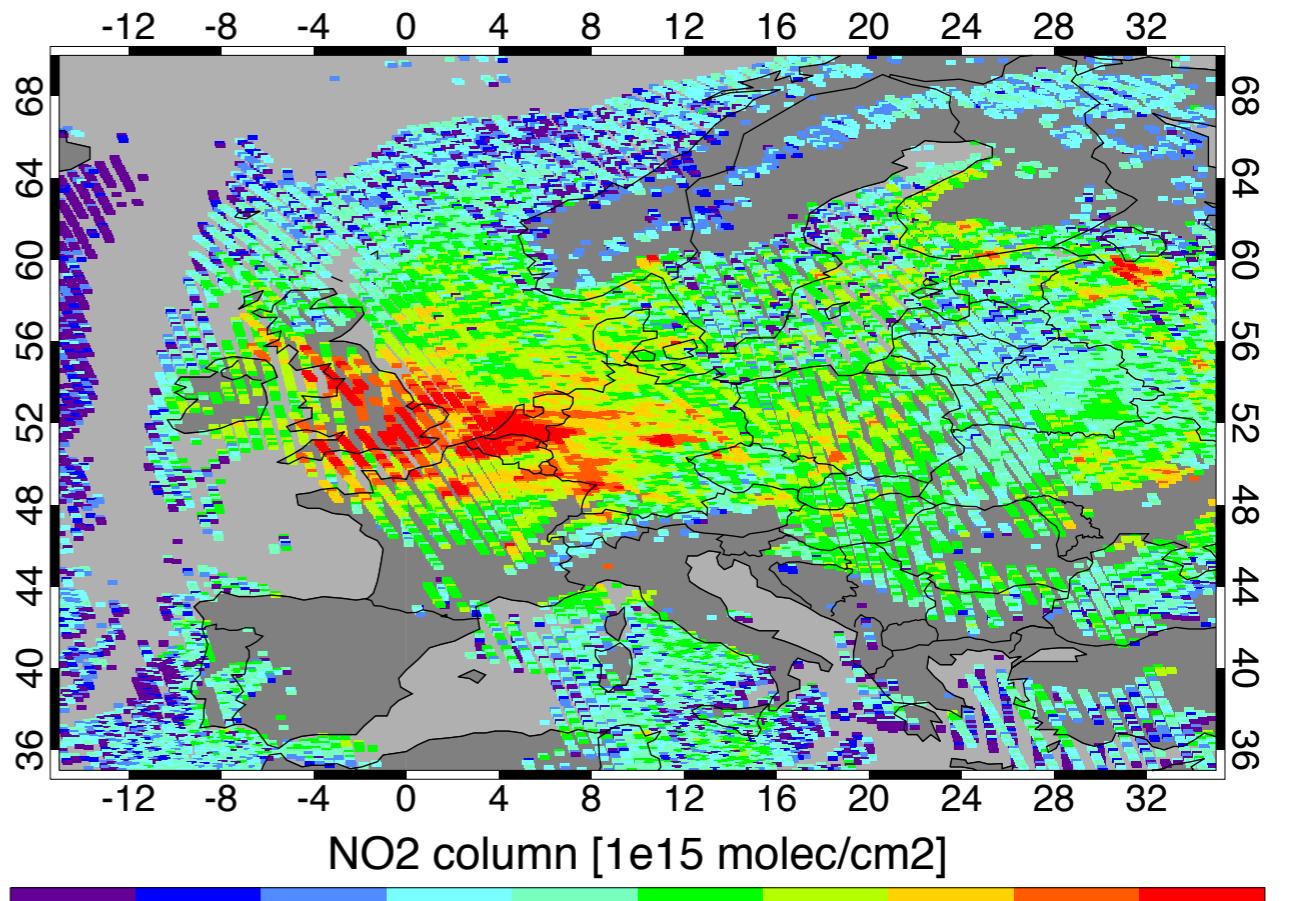
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Free model, LE v1.6

OMI NO₂

[NO₂ column] OMI, omi010, 20070327



Analysis (NO_x emission adjustment)



Emission scaling factor
averaged over 5 week
period

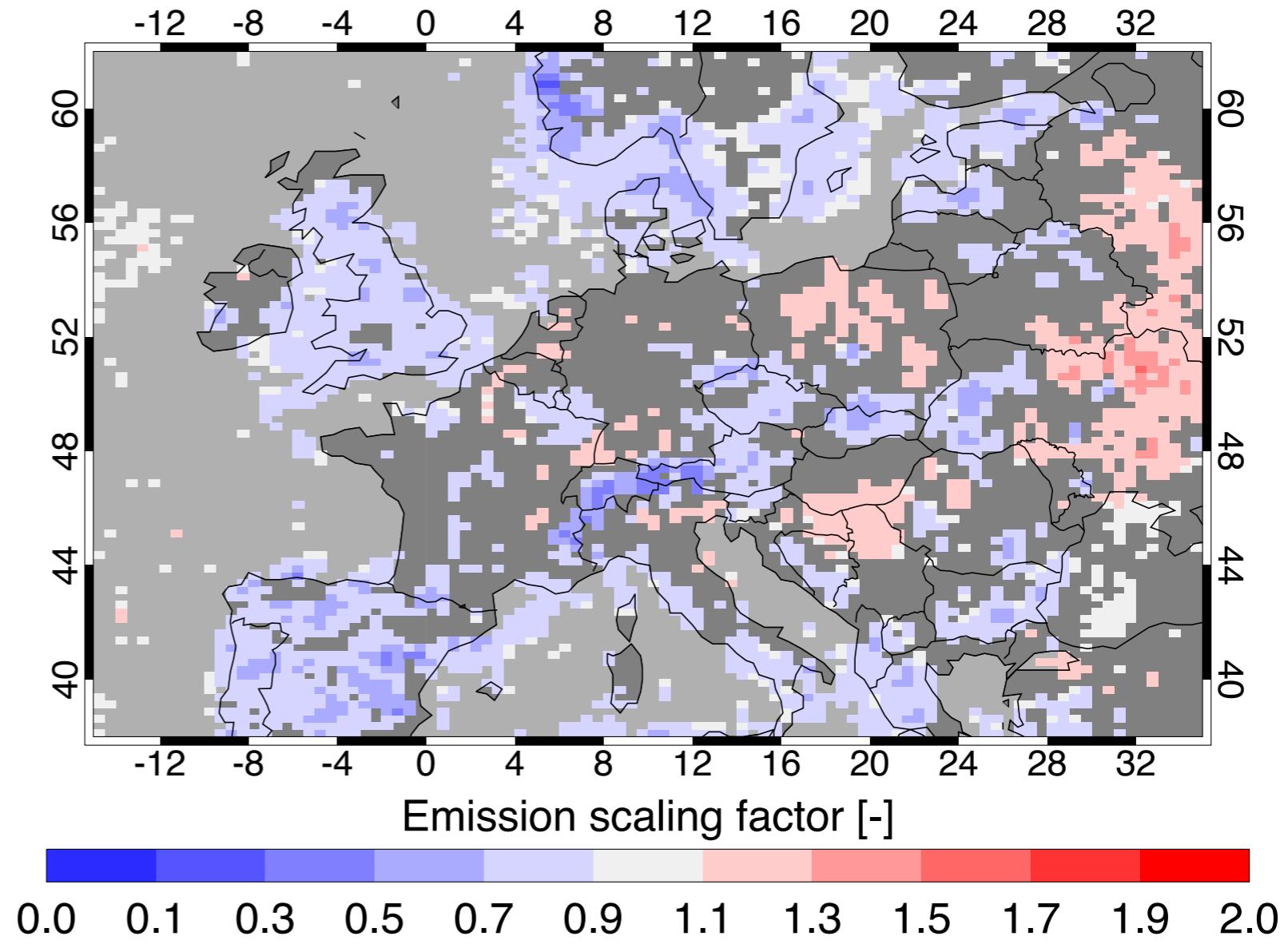
DOMINO v2 data

Nearly cloud free obs ->
About 20 independent
emission estimates per
location

Only significant > 2 σ points

NO_x emission adjustment factor

[Noise 1] v1.6 omi010, 20070323-20070429

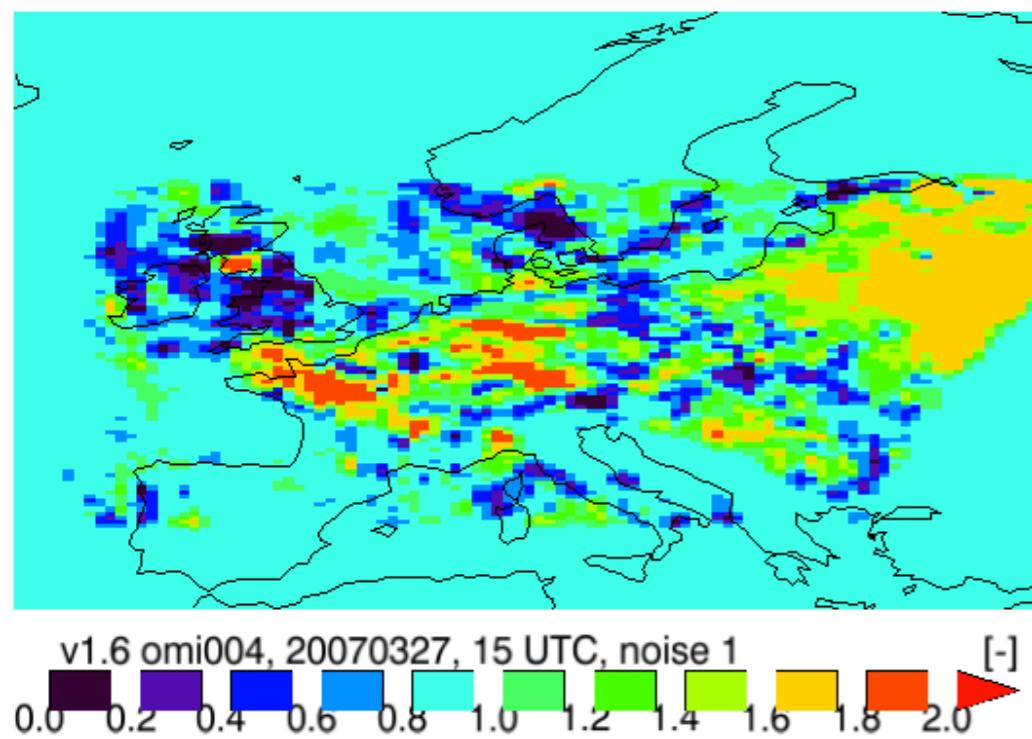


Adding noise to other model parameters

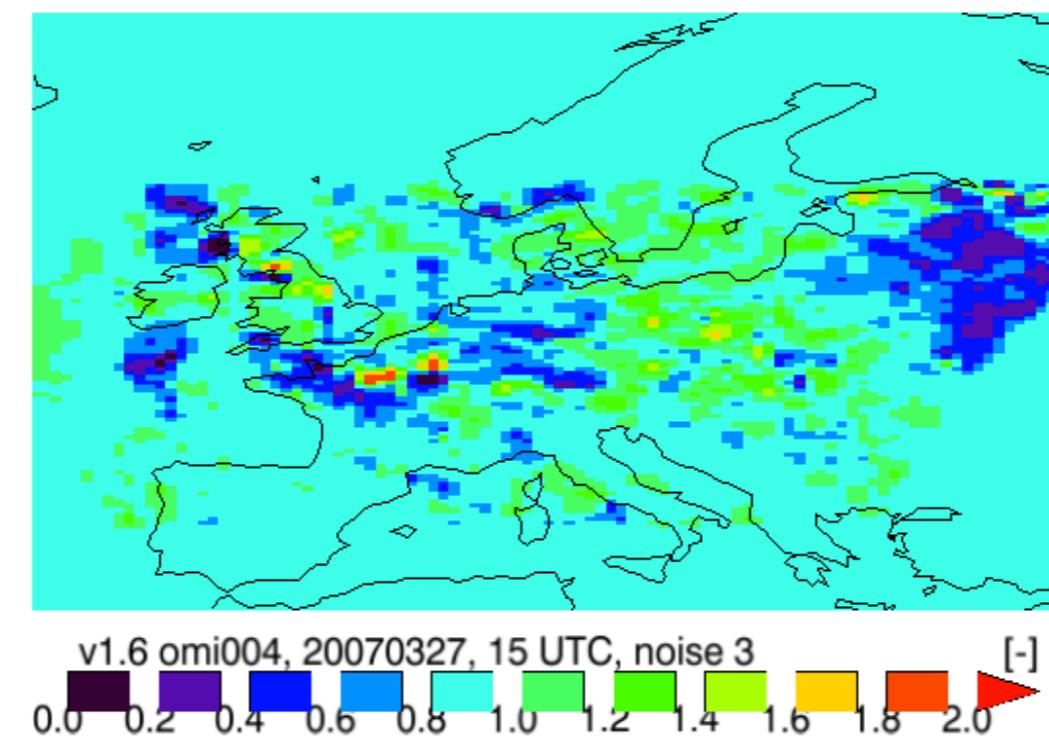


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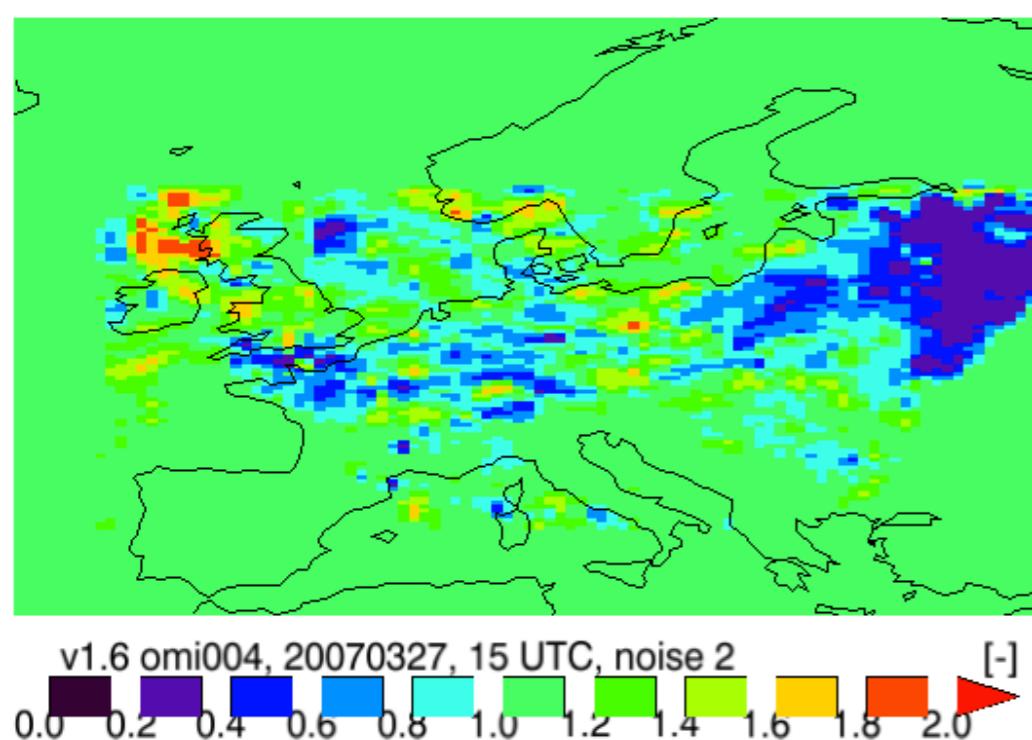
NOx emissions



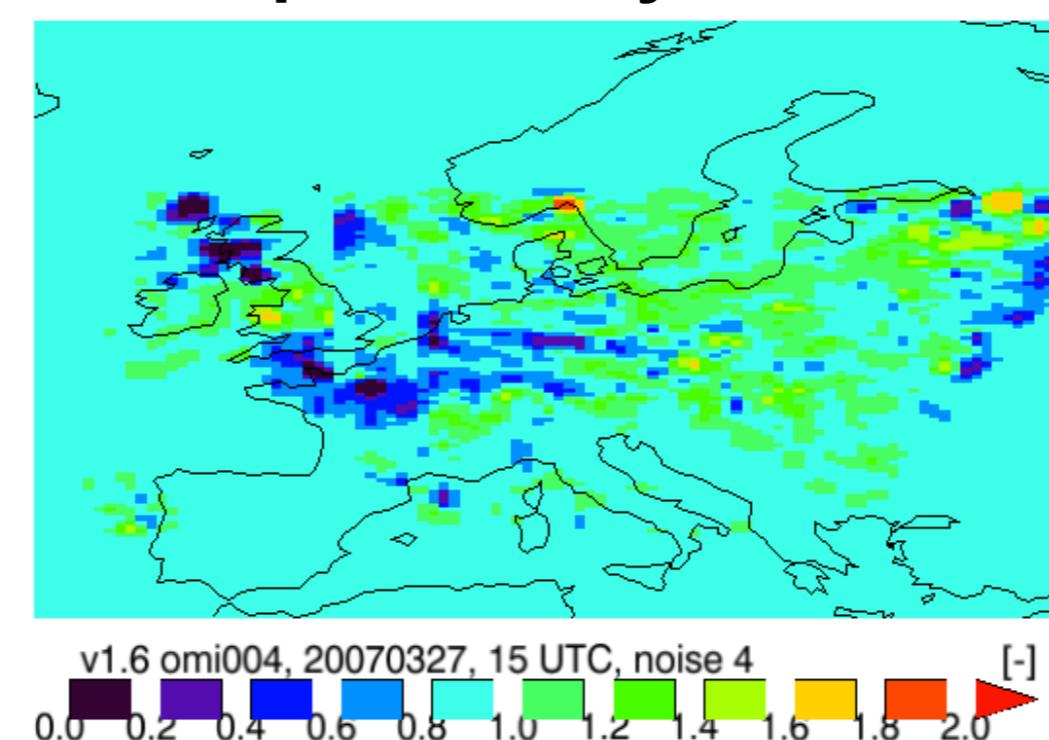
O3 deposition



VOC emissions



O3 top boundary



Noise factors:
NOx emission
VOC emission
O3 deposition
O3 top

27 March 2007



Assimilation OMI NO₂ - impact on ozone

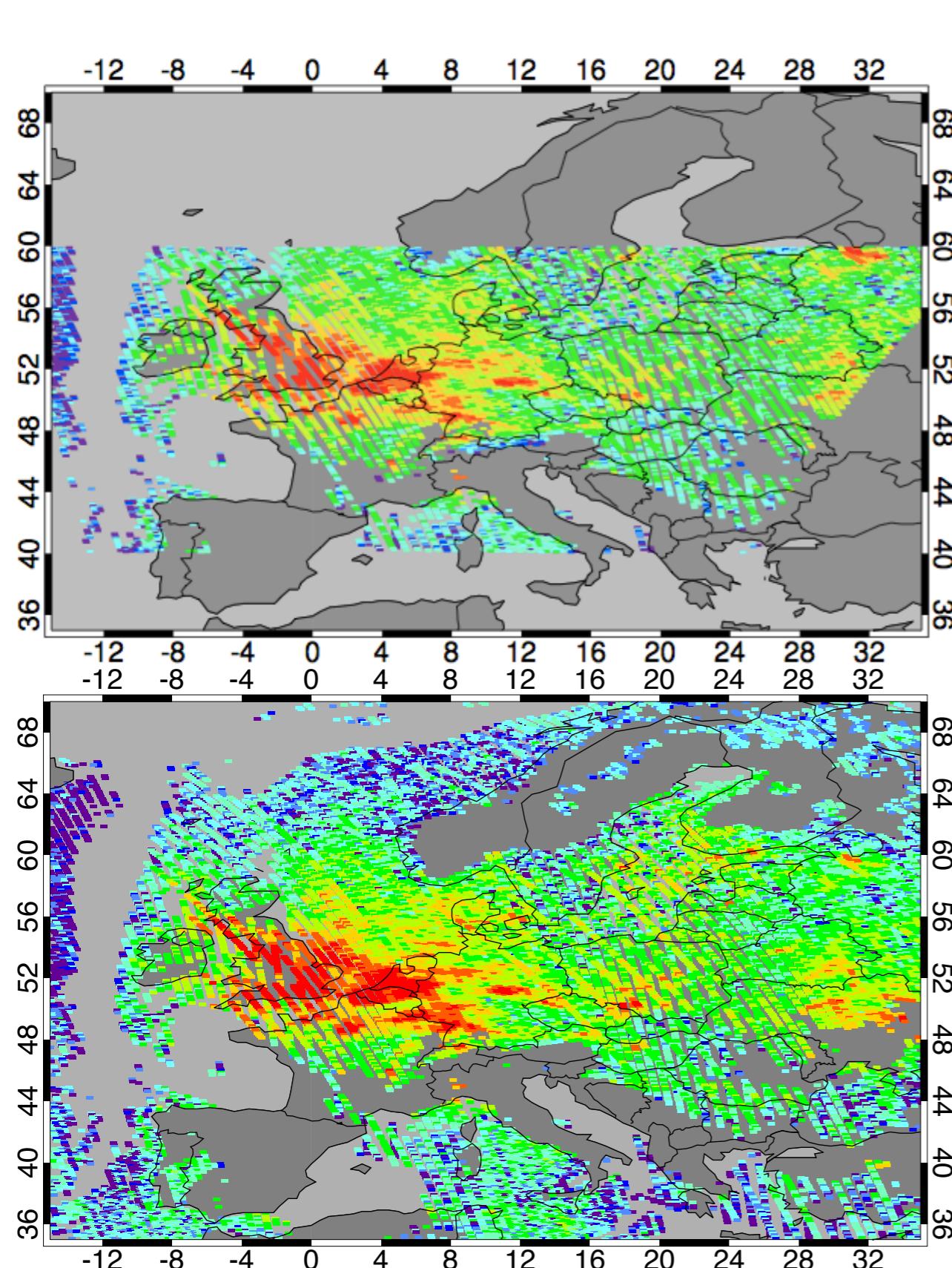
Statistics, ozone peak value	Free run	OMI analysis
Normalised Mean Bias, NL	0,05	0,04
Normalised Mean Bias, FR	-0,03	-0,03
Normalised Mean Bias, DE	-0,08	-0,08
Fractional Gross Error, NL	0,16	0,16
Fractional Gross Error, FR	0,13	0,13
Fractional Gross Error, DE	0,14	0,13
Correlation, NL	0,66	0,69
Correlation, FR	0,70	0,72
Correlation, DE	0,67	0,70

Only NOx emissions adjusted

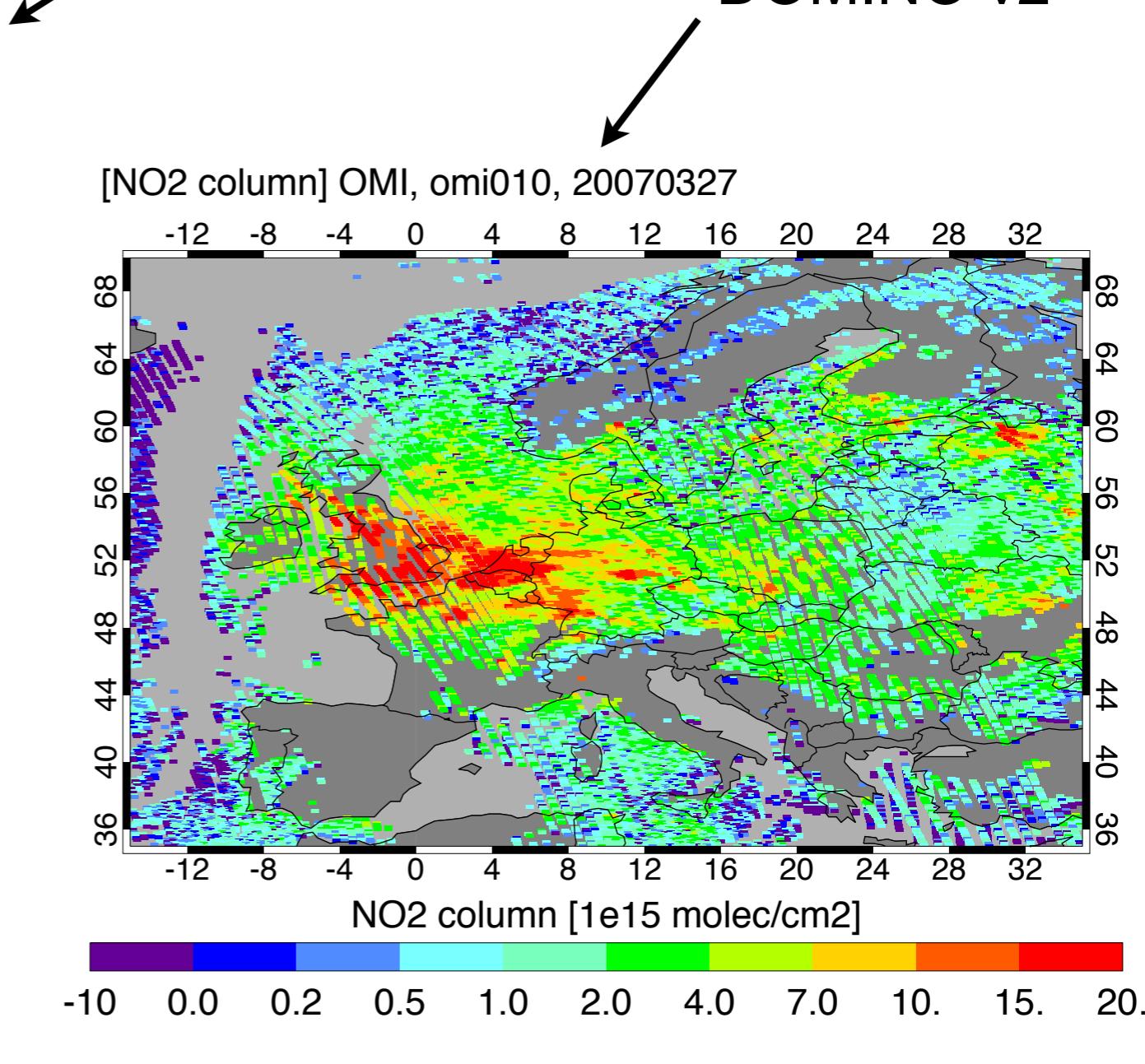
Different OMI NO₂ retrieval products



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EOMINO (EMPA)

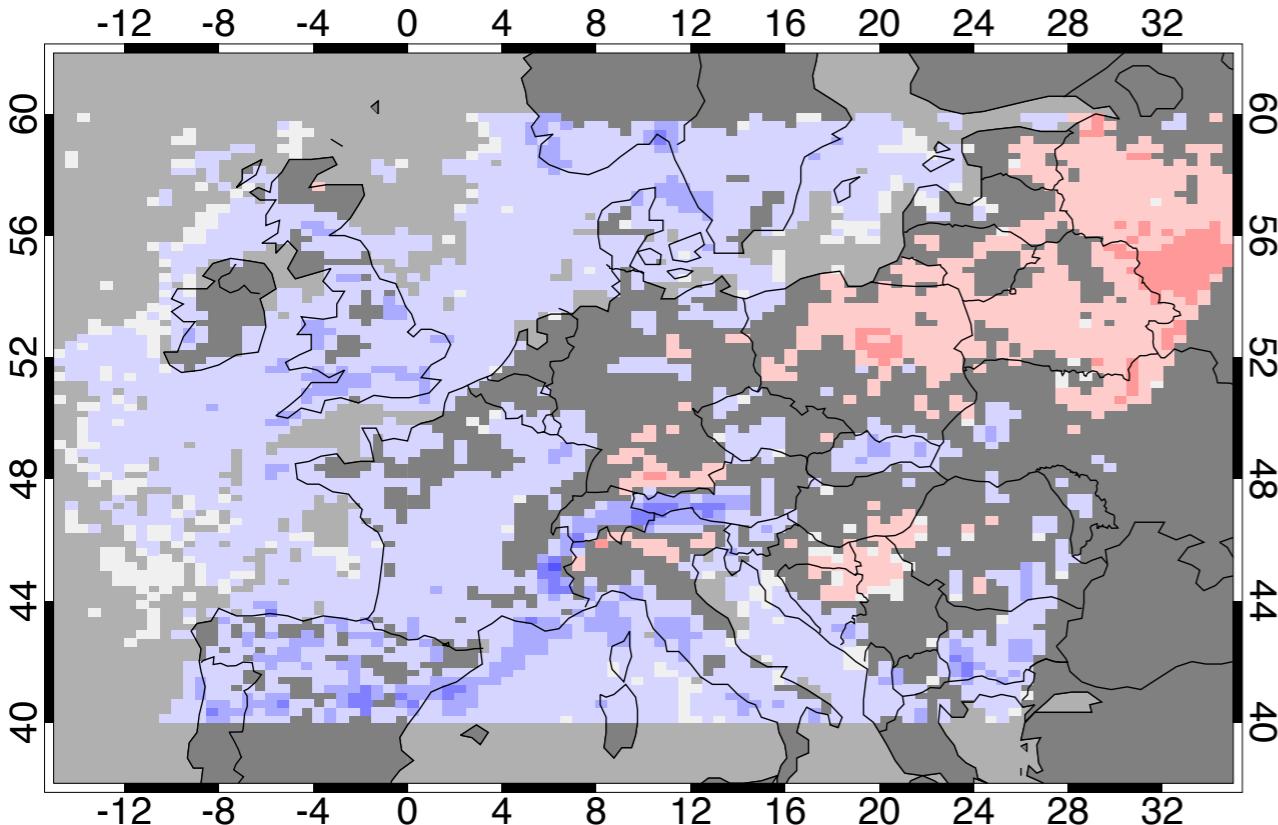


DOMINO v1

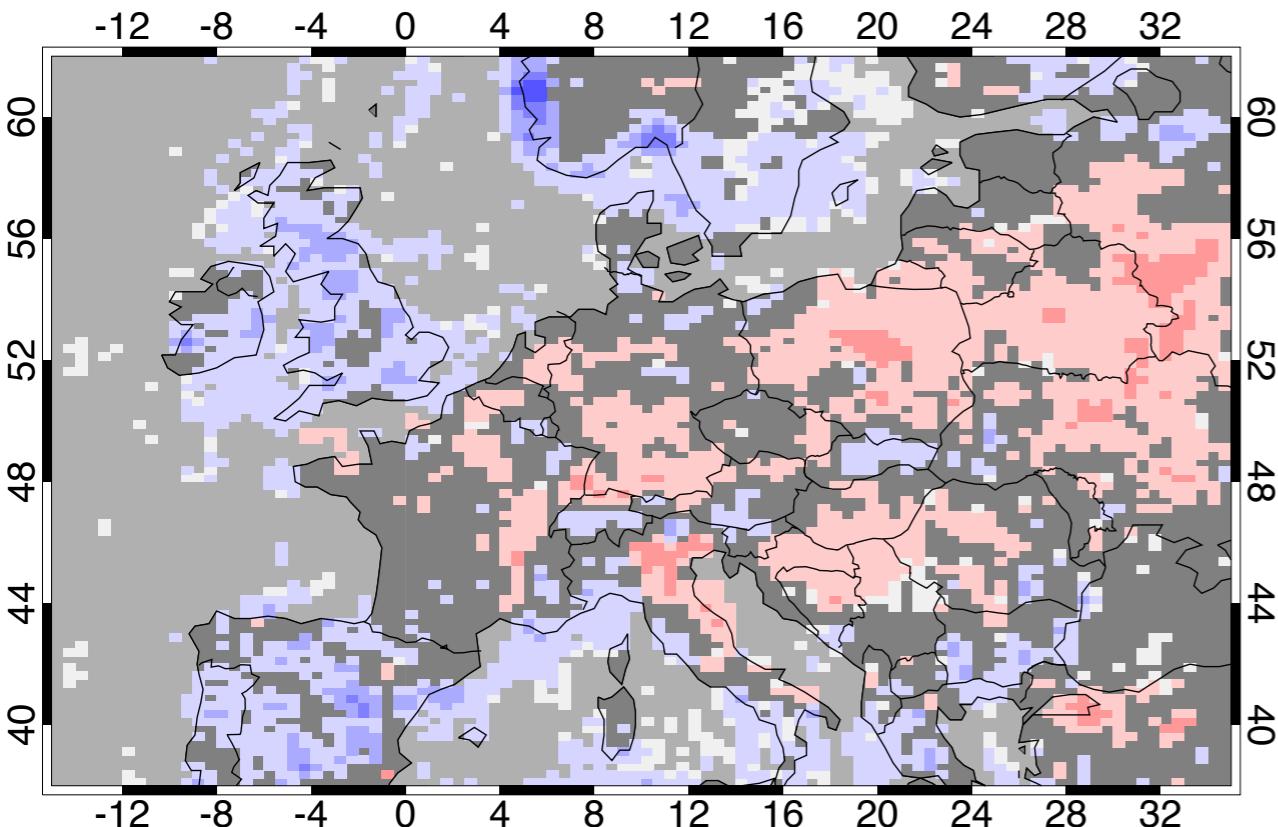
Sensitivity of emission to OMI retrieval algo



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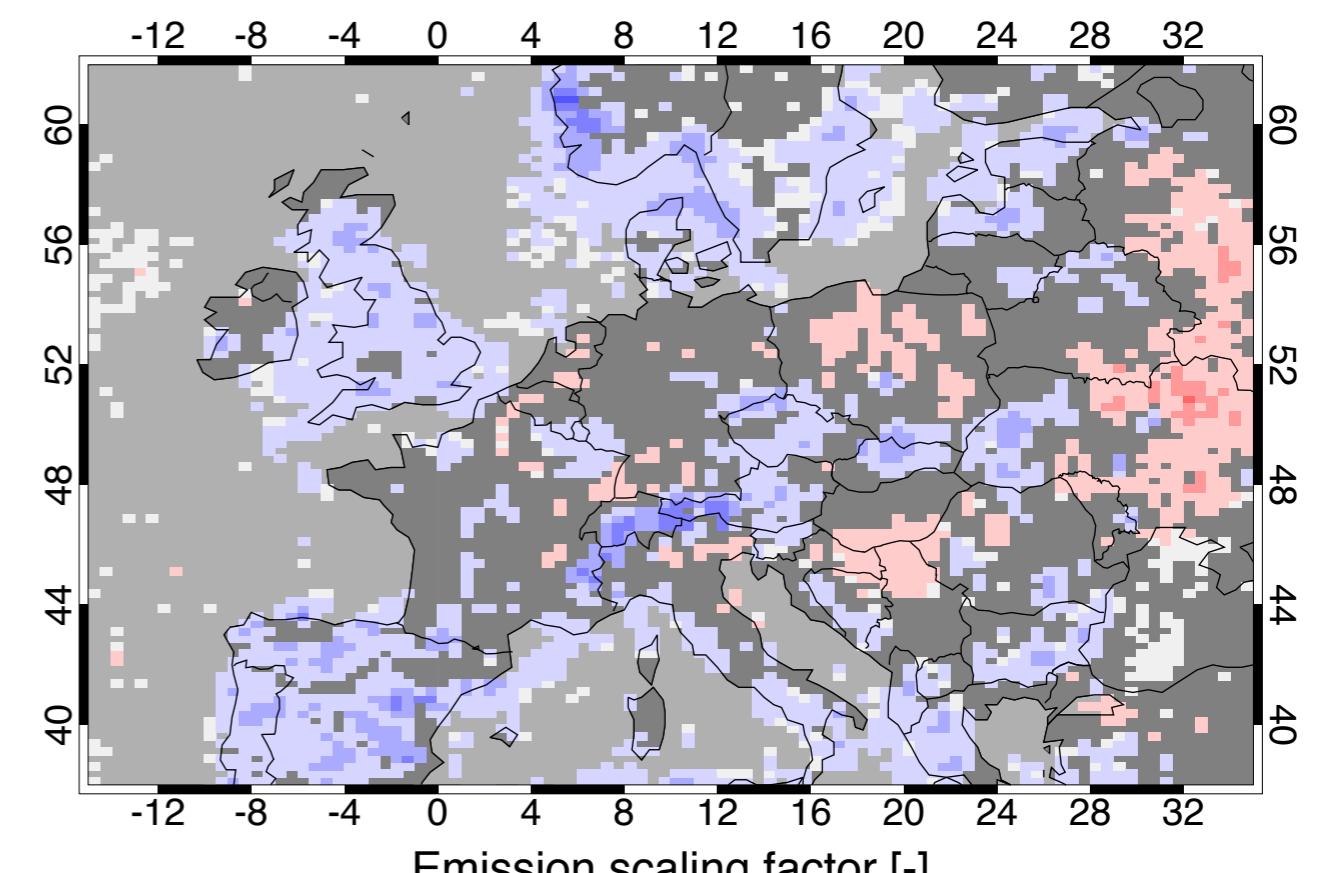


EOMINO (EMPA)

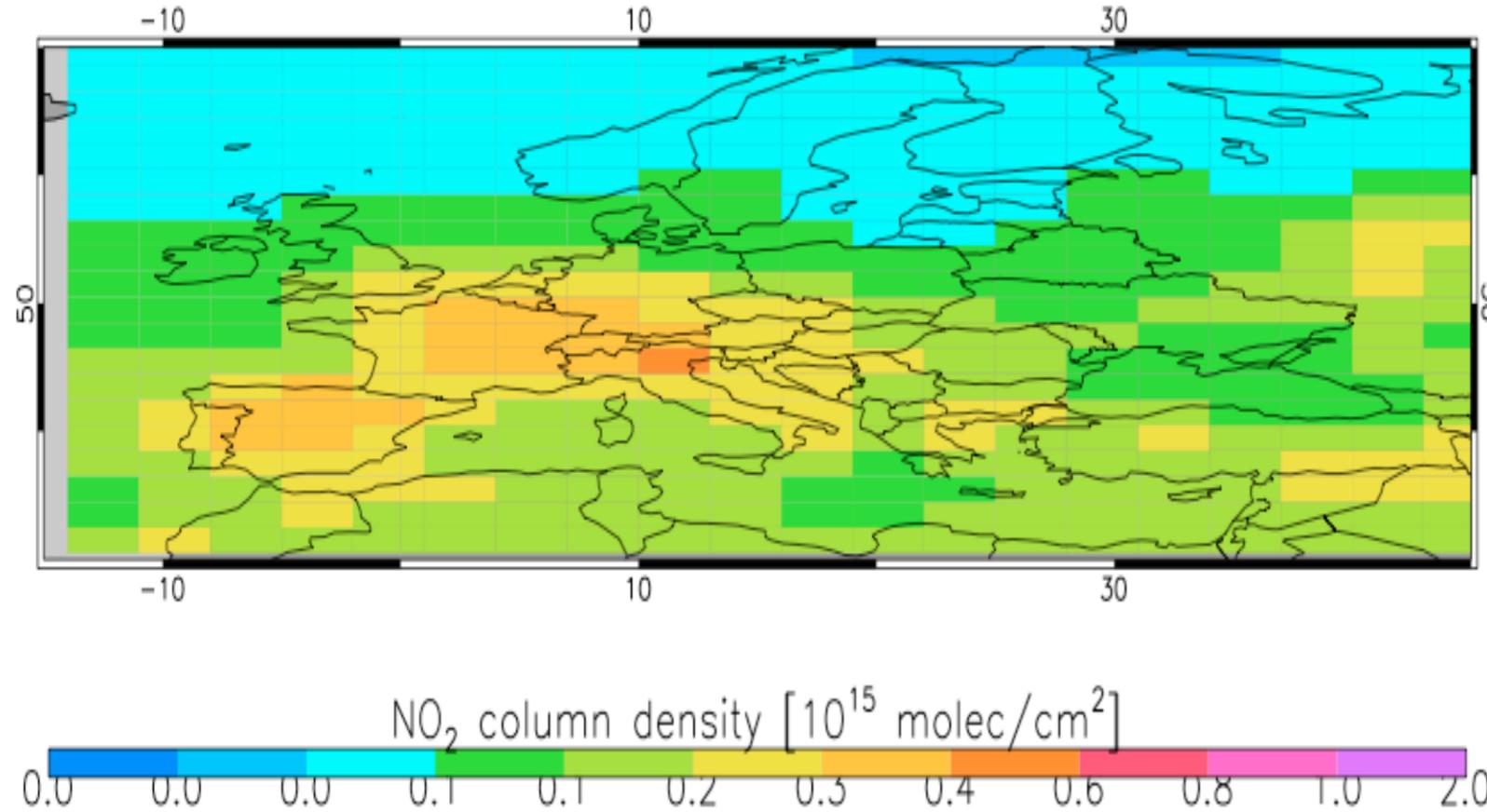


DOMINO v1

[Noise 1] v1.6 omi010, 20070323-20070429



Free troposphere NO₂ - TM5 estimate

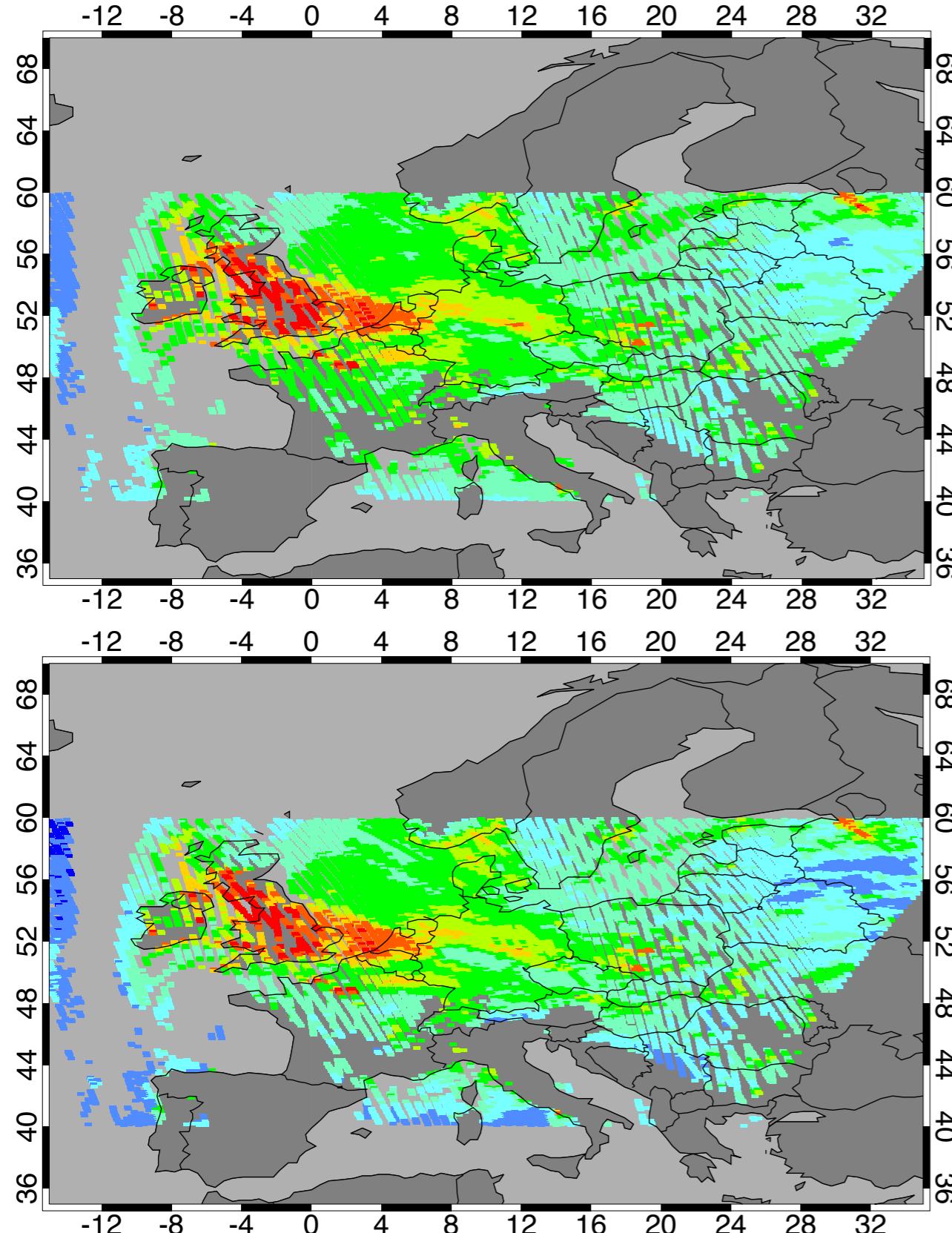


Partial columns of NO₂, april 2007 monthly mean between 3500m (670 hPa) and the (ozone) tropopause, based on the "decadal" runs, with the ERA-interim meteo from ECMWF, and the benchmark TM5 model, Huijnen et al. 2010

Impact of adding free troposphere



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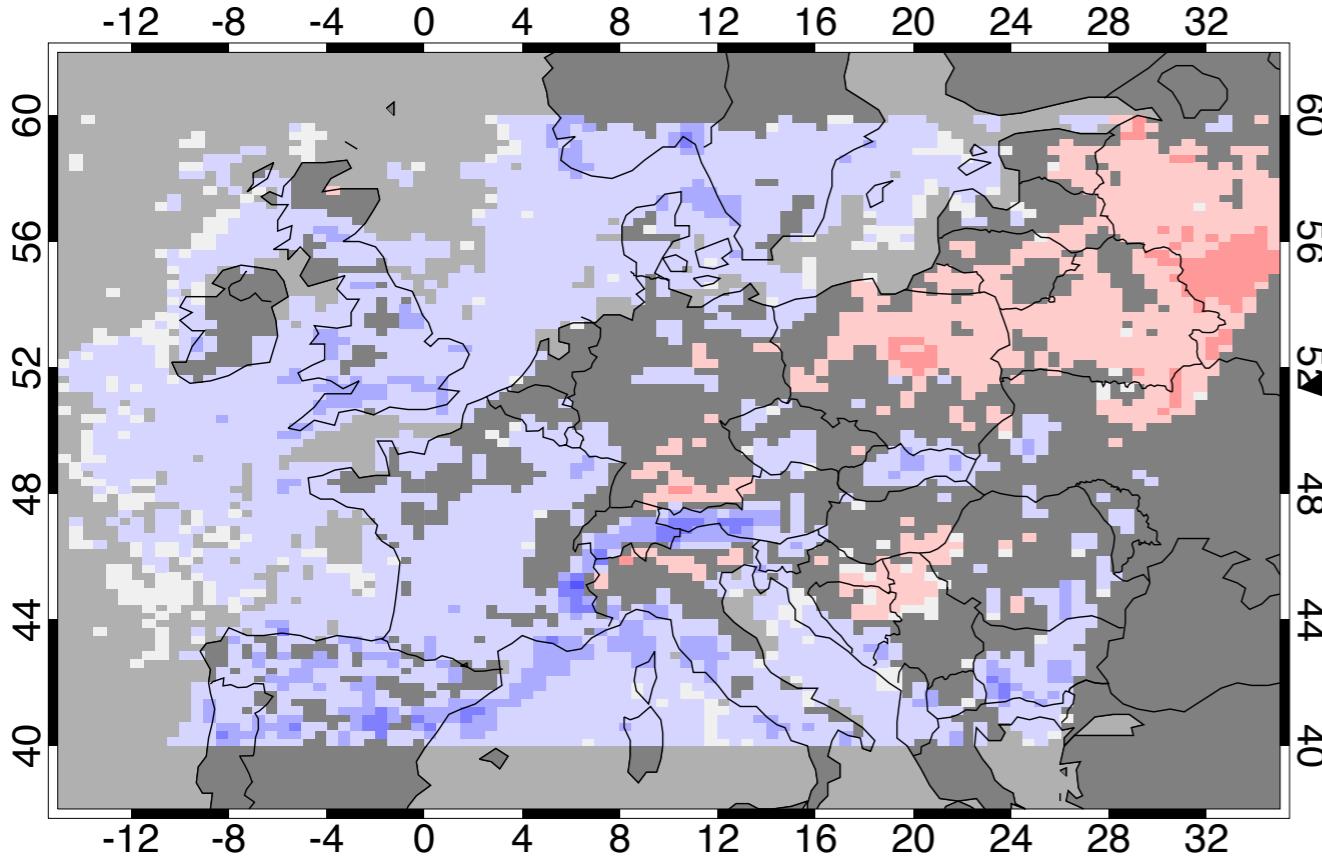
Including free troposphere
from TM5

Without upper troposphere

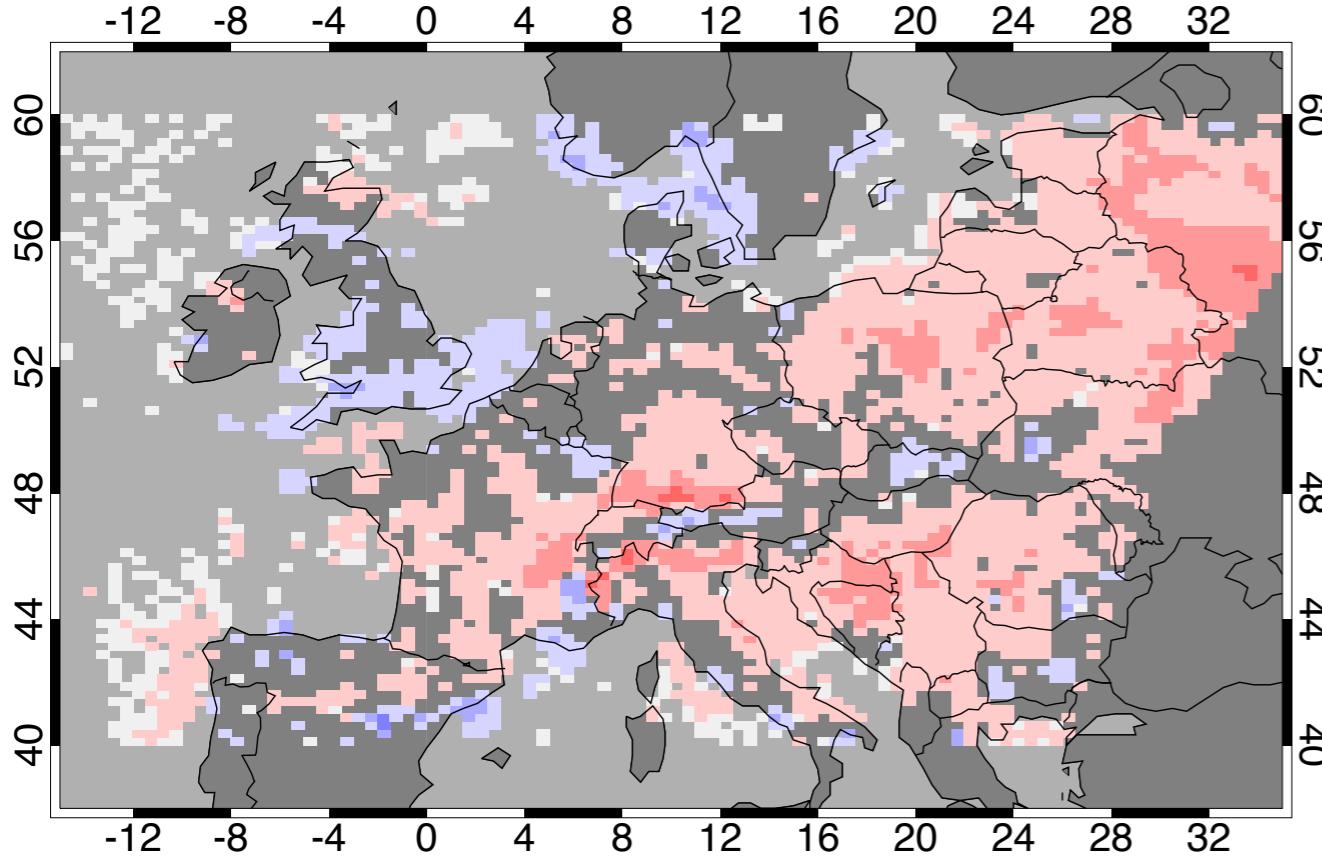
Impact of adding free troposphere



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Free trop from TM5



Without upper troposphere

Emission scaling factor [-]

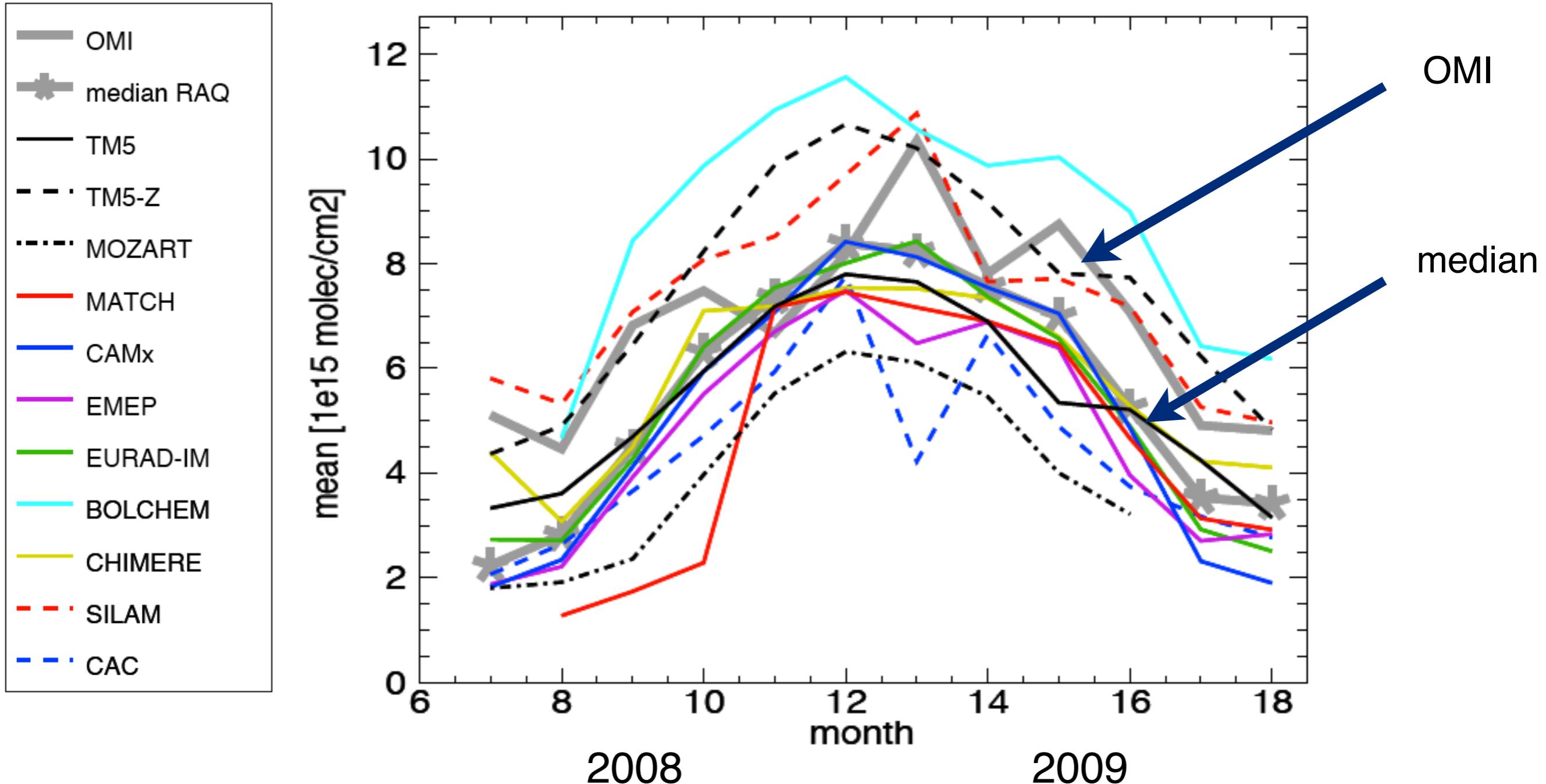


OMI NO₂ versus AQ ensemble (GEMS/MACC)



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region western_Europe





Wrap up

Findings

- Overall reasonable quantitative comparison OMI and Lotos-Euros, 30-50% level
- OMI NO₂ has good impact on LE emissions:
 - by emission tuning LE is able to reproduce the OMI features
- NO_x emission adjustments shows robustness over the 5 week assimilation
 - signal is rather smooth - no clear sign of hotspots
- No large impact on ozone: similar scores (slightly better correlation)
- East-European emissions seem to be low, possibly soil emissions play role

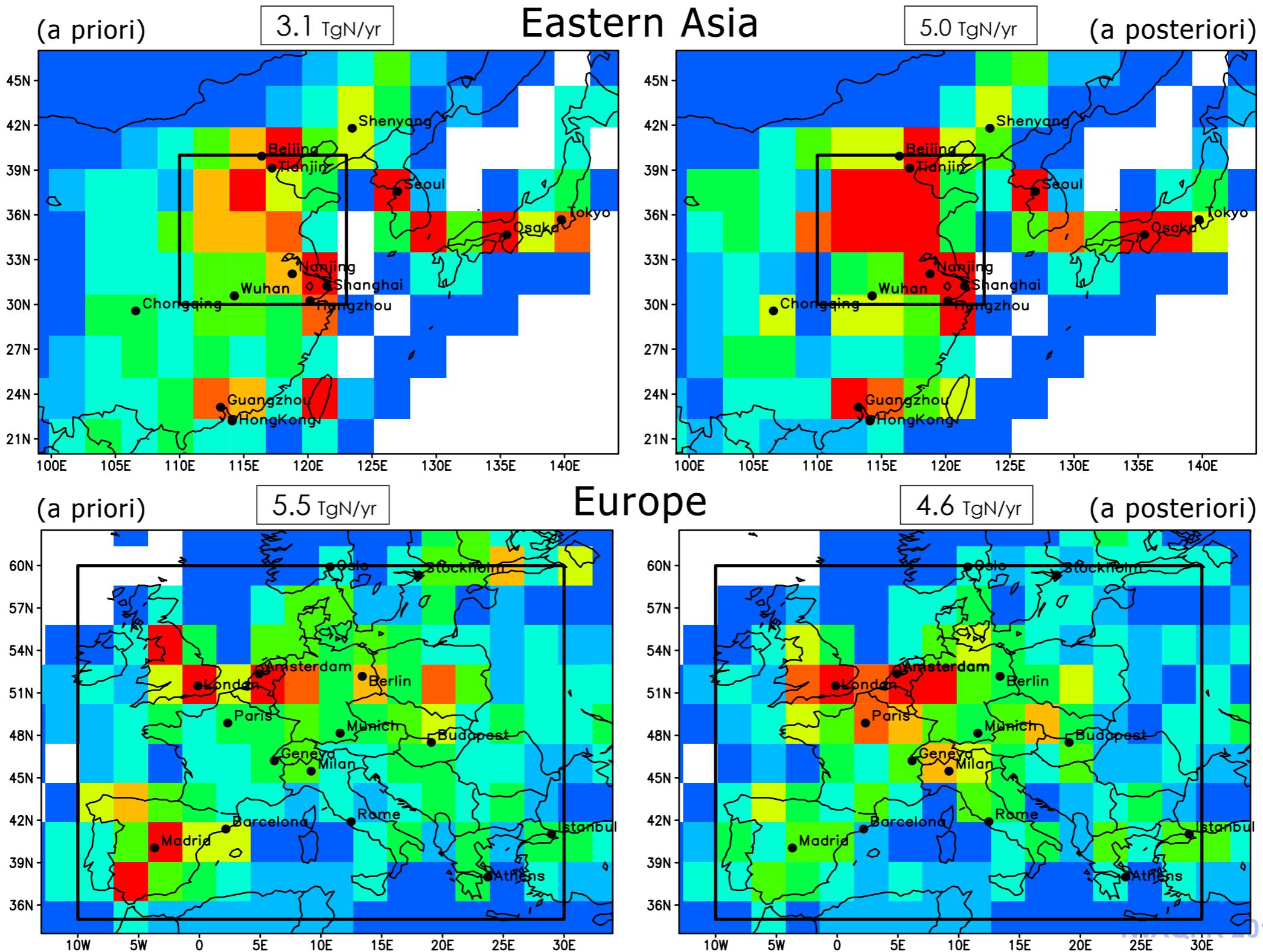
Can we improve European emission inventories with satellite observations?

Issues / sensitivities:

- Retrieval products differ (DOMINO 1 & 2, EOMINO, others), uncertainty large impact on emissions
- Which part of model to blame ? (NO_x emissions, VOC, O₃-top, O₃-depos, ...)
- Free troposphere
- Seasonality model vs measurements

Global NO_x emission estimates from OMI NO₂ data and ensemble Kalman filter data assimilation

Miyazaki, K. and H. Eskes ([O29](#))



Assimilation OMI NO₂ - setup



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LE v1.6.002, runs “omi003-007”

003:

- Assimilation of DOMINO v1.02 data
- Period: 20 March - 19 April 2007
- MACC domain, 0.5x0.25 resolution
- Airbase surface ozone data are monitored by the assimilation system
- NO_x, VOC, O₃top, O₃vd

004:

- EMPA EOMINO v1 data

007:

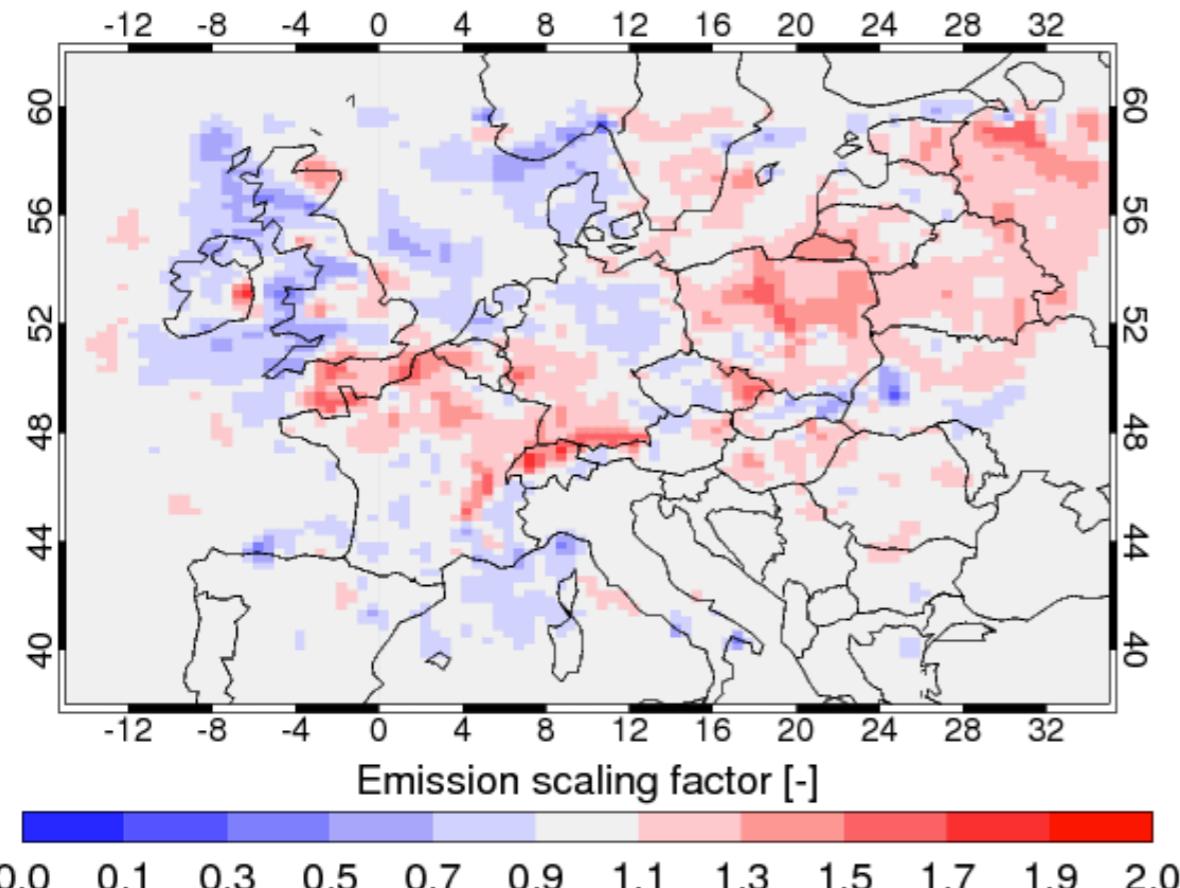
- only NO_x emissions are adjusted

Assimilation OMI NO₂ - 26 mar + 2 apr



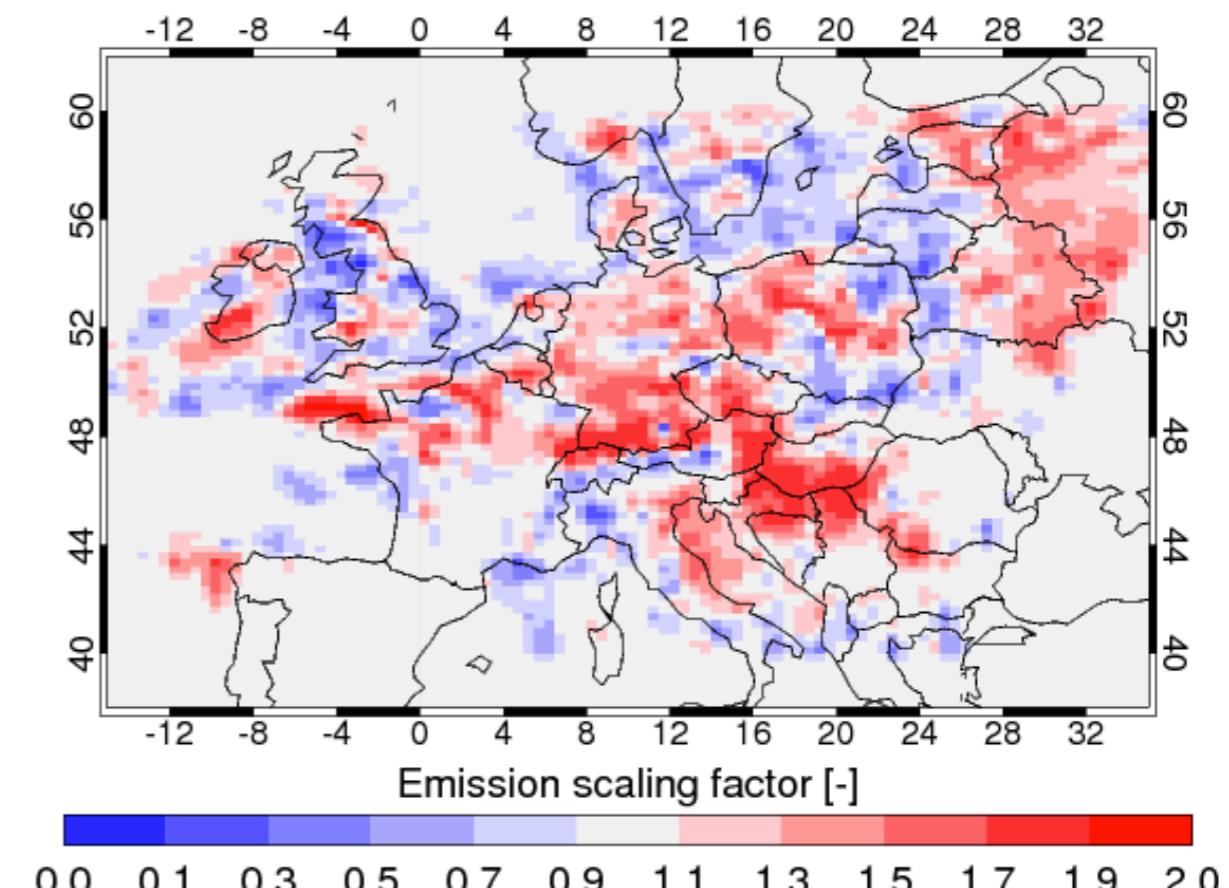
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[Noise 1] v1.6 omi007, 20070326, 15 UTC



26 March

[Noise 1] v1.6 omi007, 20070402, 15 UTC



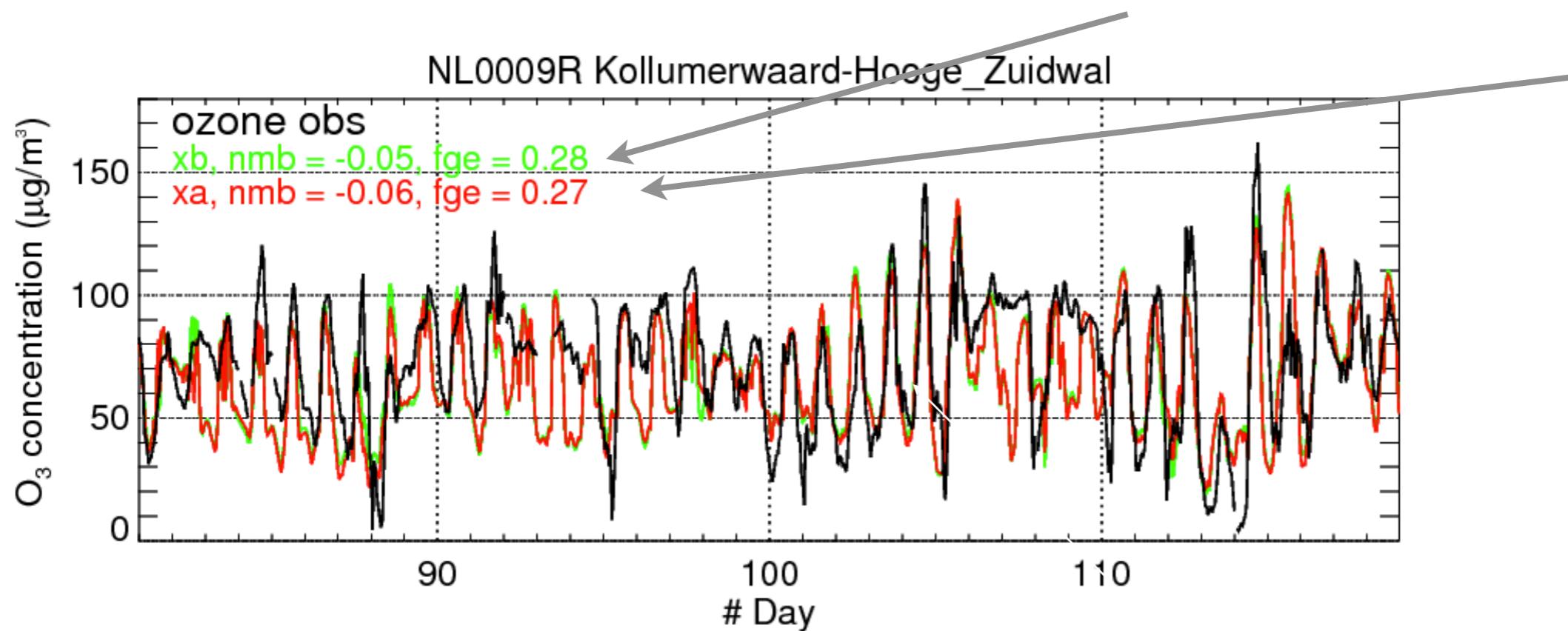
2 April

NO_x emission adjustment
Exp OMI-007

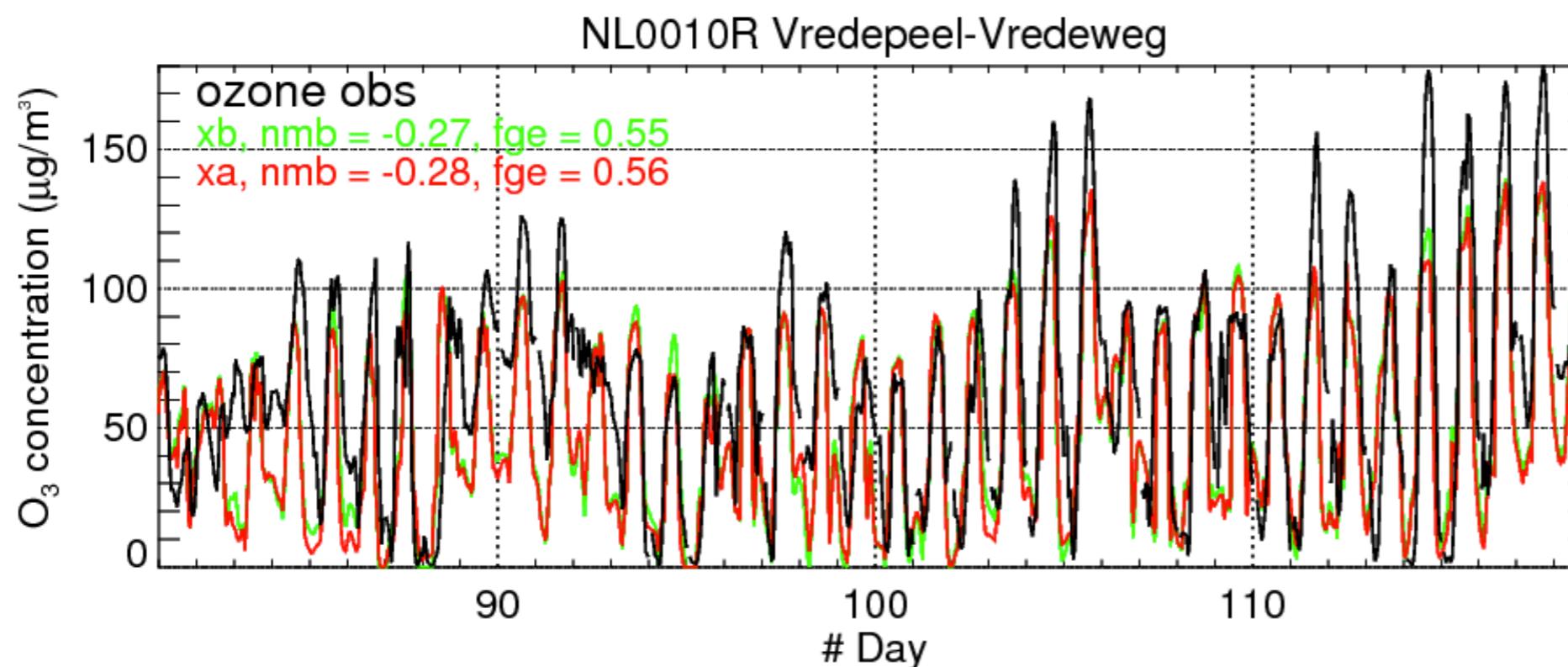
Assimilation DOMINO - impact on ozone

Free model, LE v1.6

Analysis



Exp OMI-007





Assimilation OMI NO₂ - impact on ozone

Statistics, ozone peak value	Free run	OMI analysis
Normalised Mean Bias, NL	0,05	0,03
Normalised Mean Bias, FR	0,00	-0,03
Normalised Mean Bias, DE	-0,07	-0,09
Fractional Gross Error, NL	0,15	0,16
Fractional Gross Error, FR	0,13	0,15
Fractional Gross Error, DE	0,13	0,15
Correlation, NL	0,64	0,62
Correlation, FR	0,77	0,72
Correlation, DE	0,65	0,56

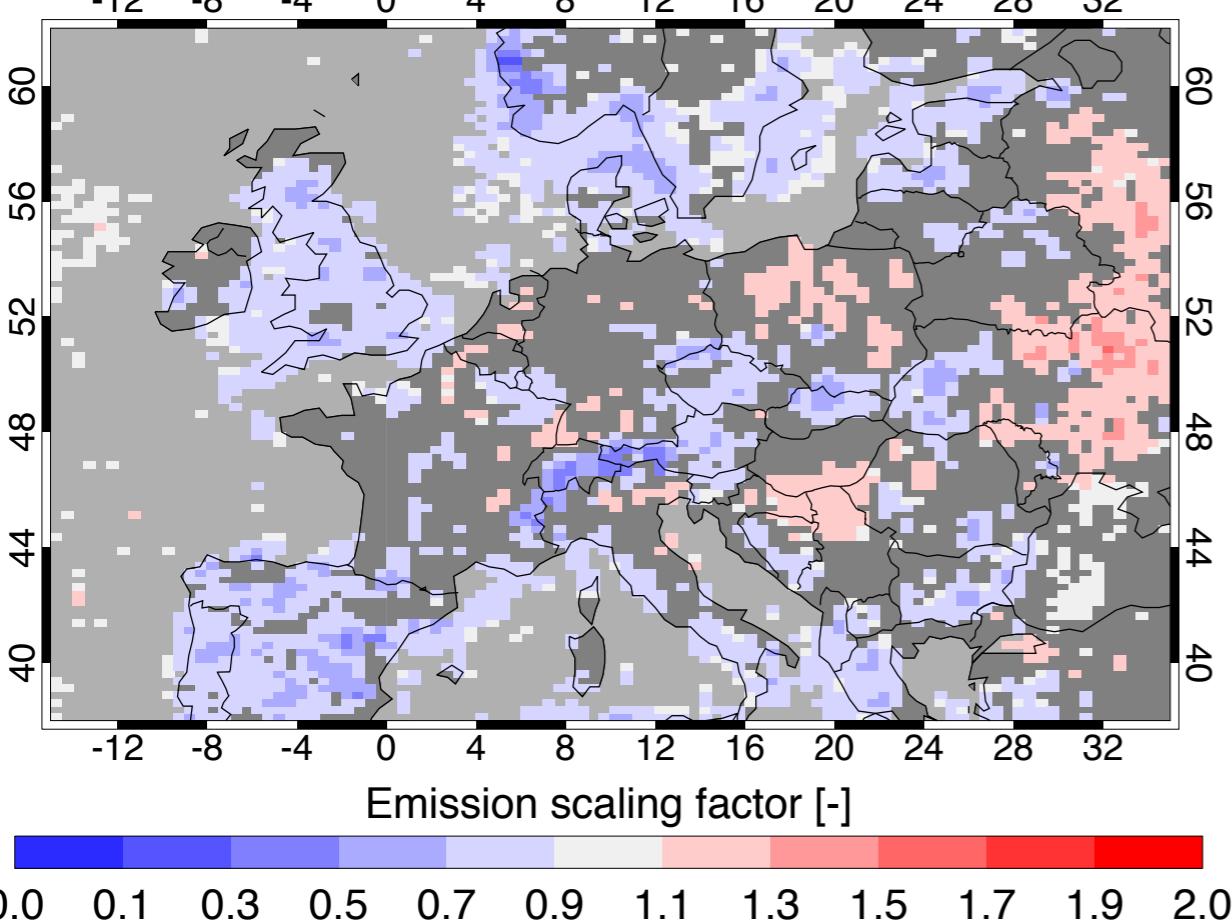
Exp OMI-003

Emission scaling factor: robustness

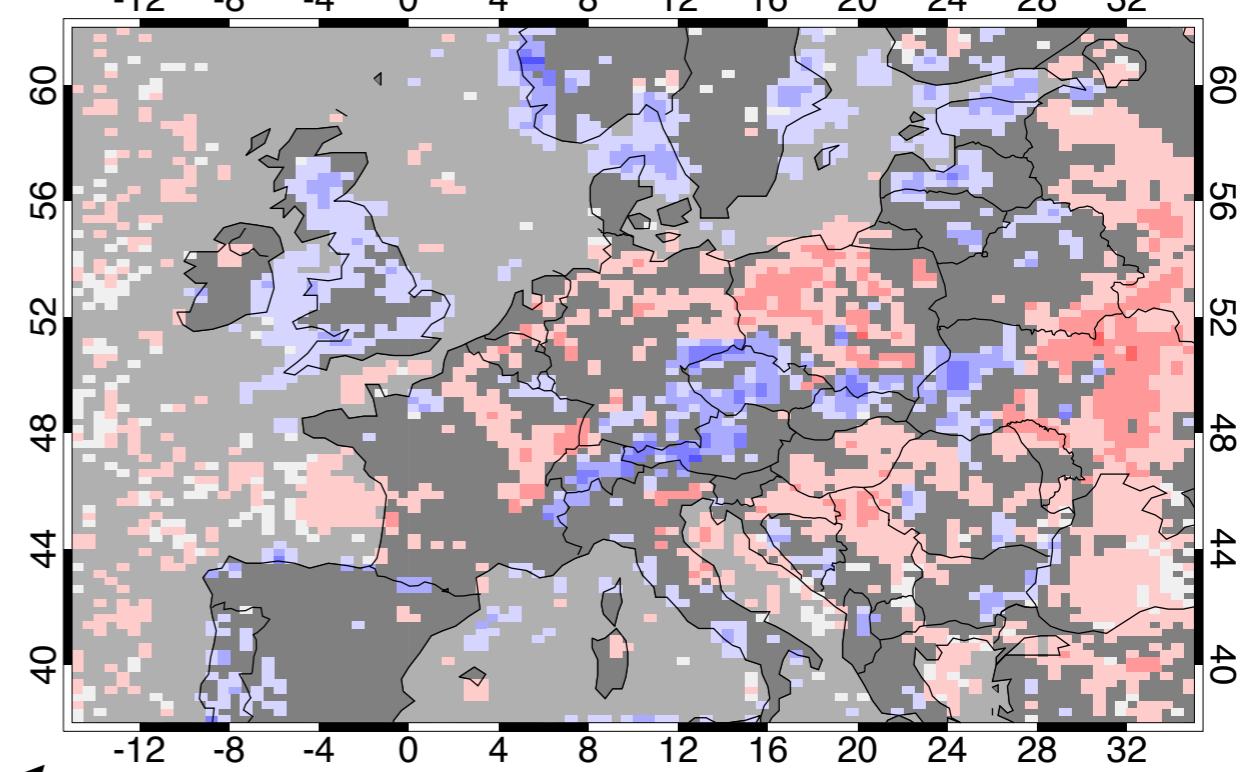


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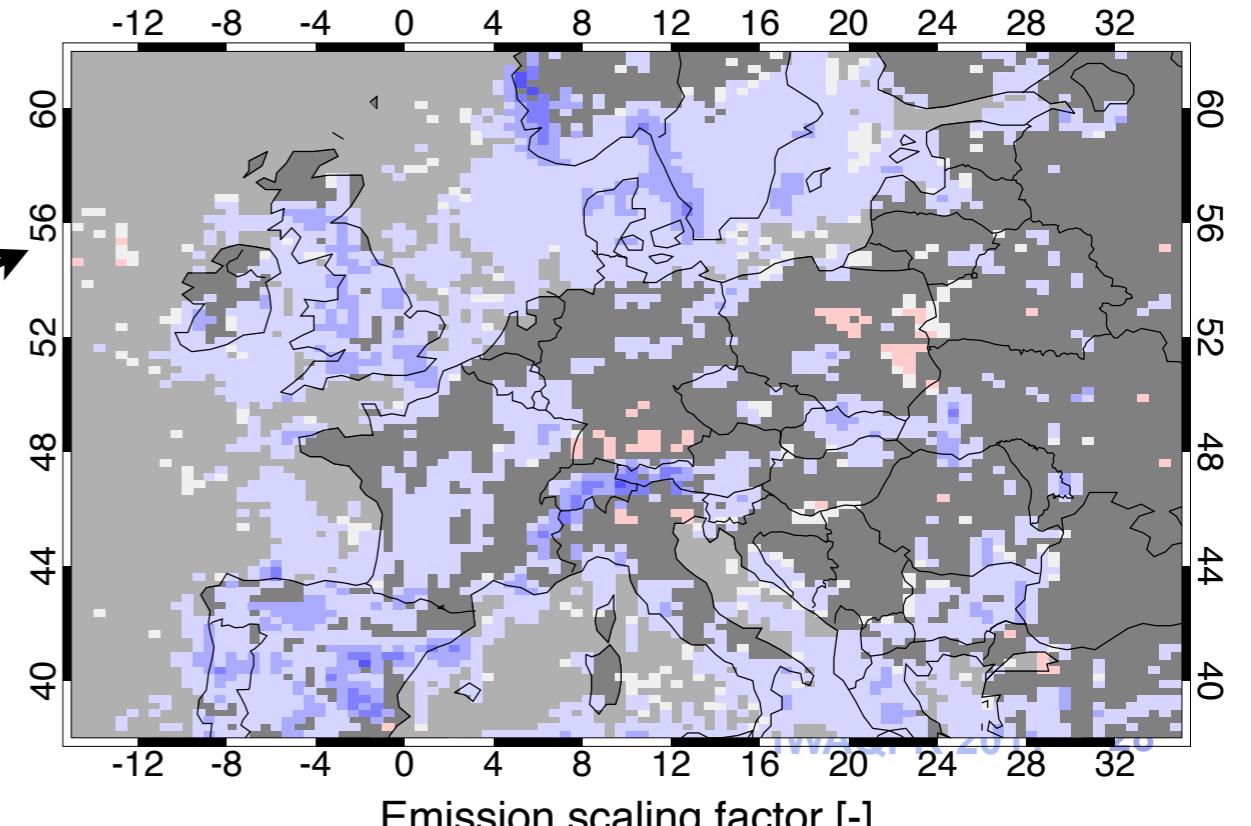
[Noise 1] v1.6 omi010, 20070323-20070429



[Noise 1] v1.6 omi010, 20070323-20070410



[Noise 1] v1.6 omi010, 20070411-20070429



Full period

First half

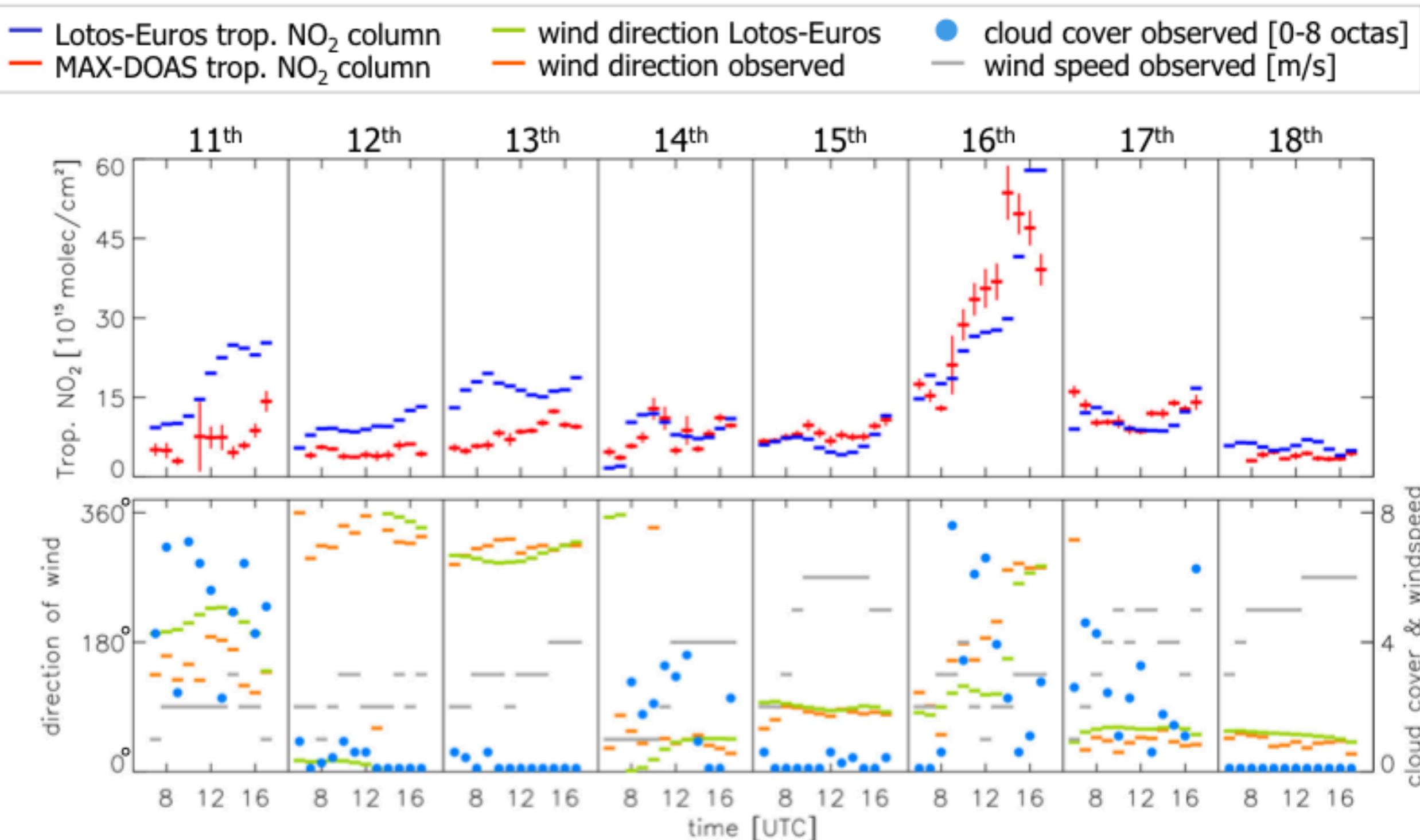
Second half

Emission scaling in first half of period compared to second half

Individual observations



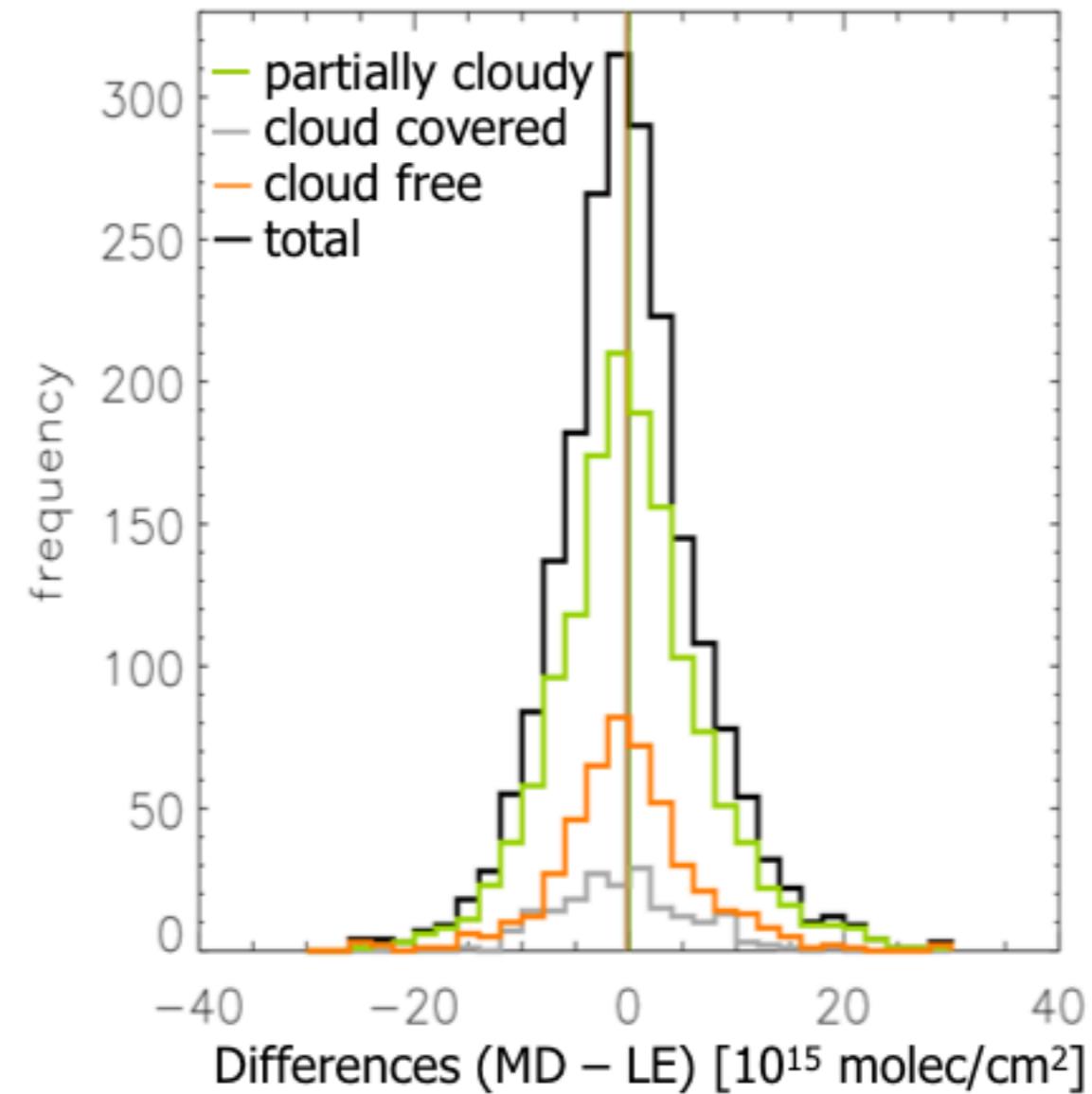
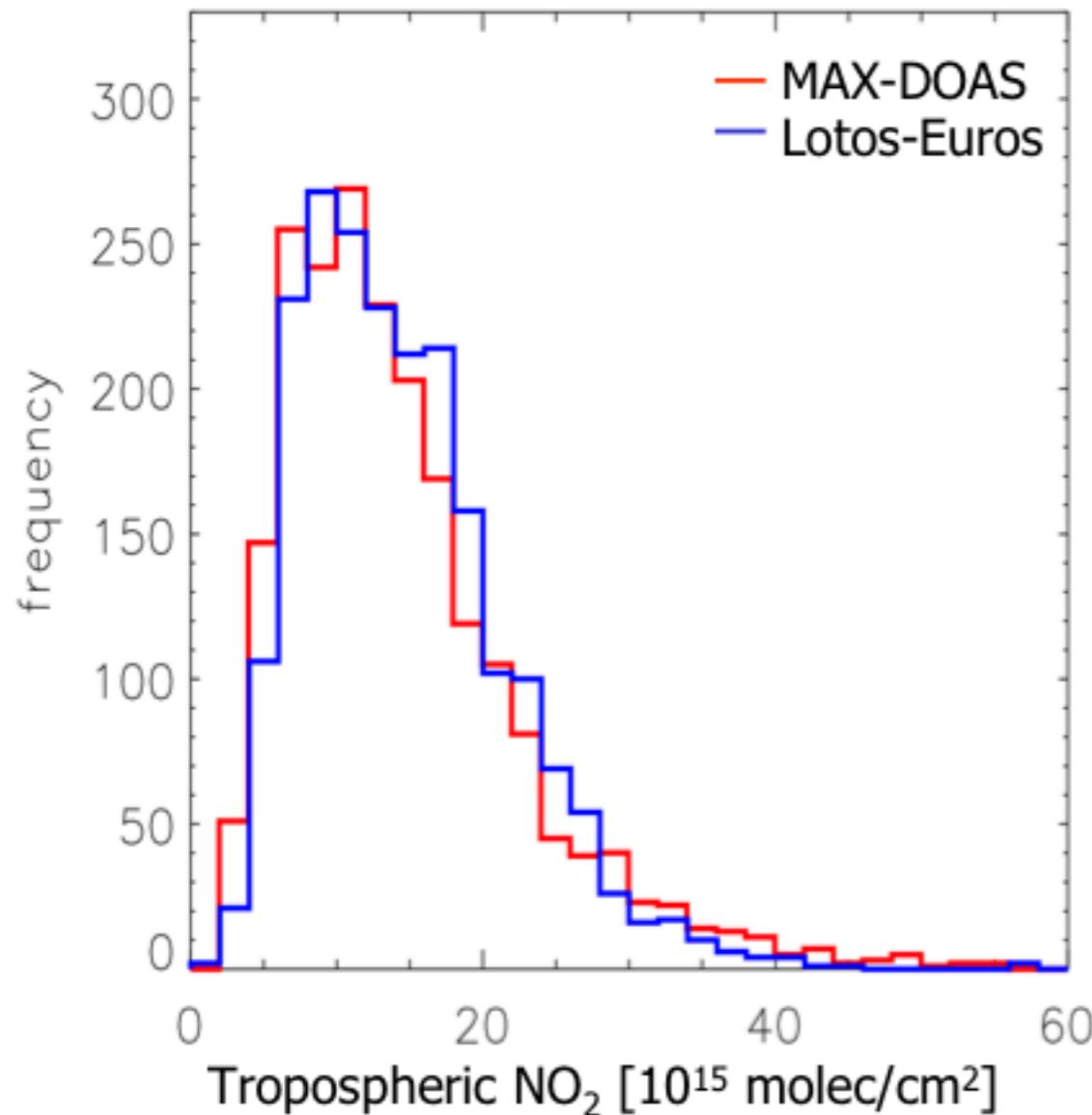
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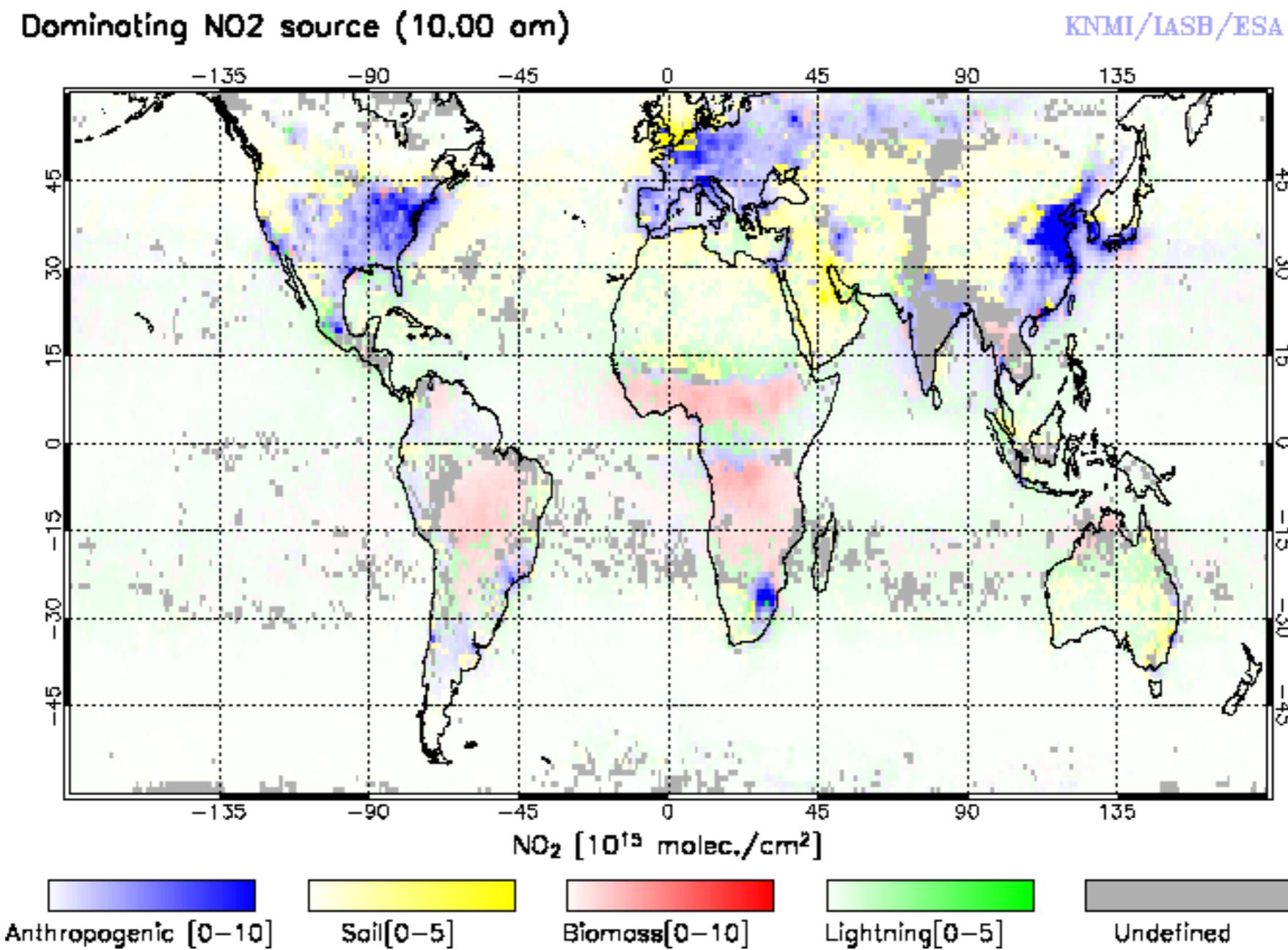


Distribution



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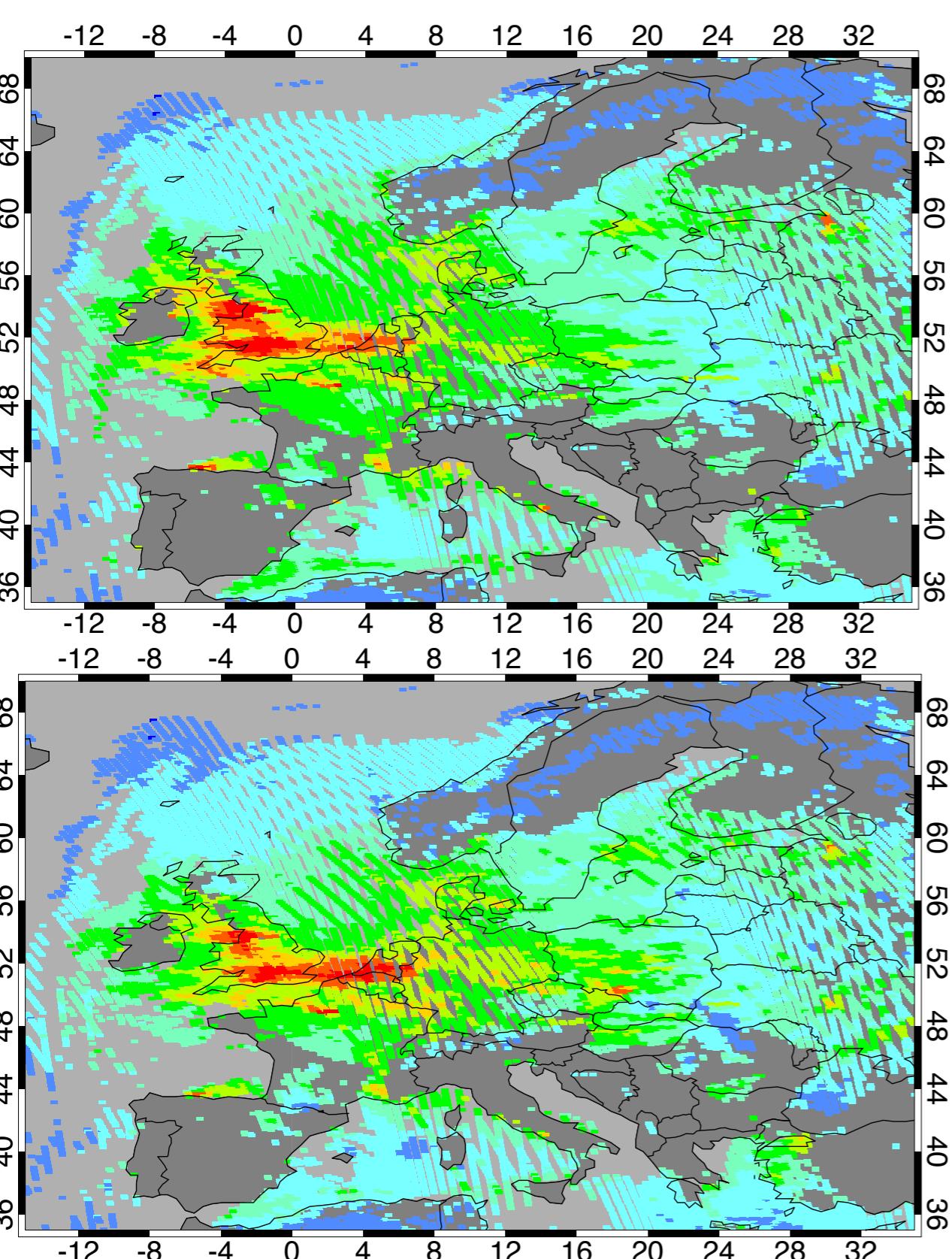




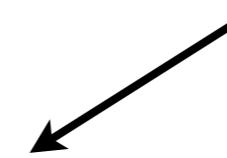
Assimilation DOMINO v2 - 26 march 2007



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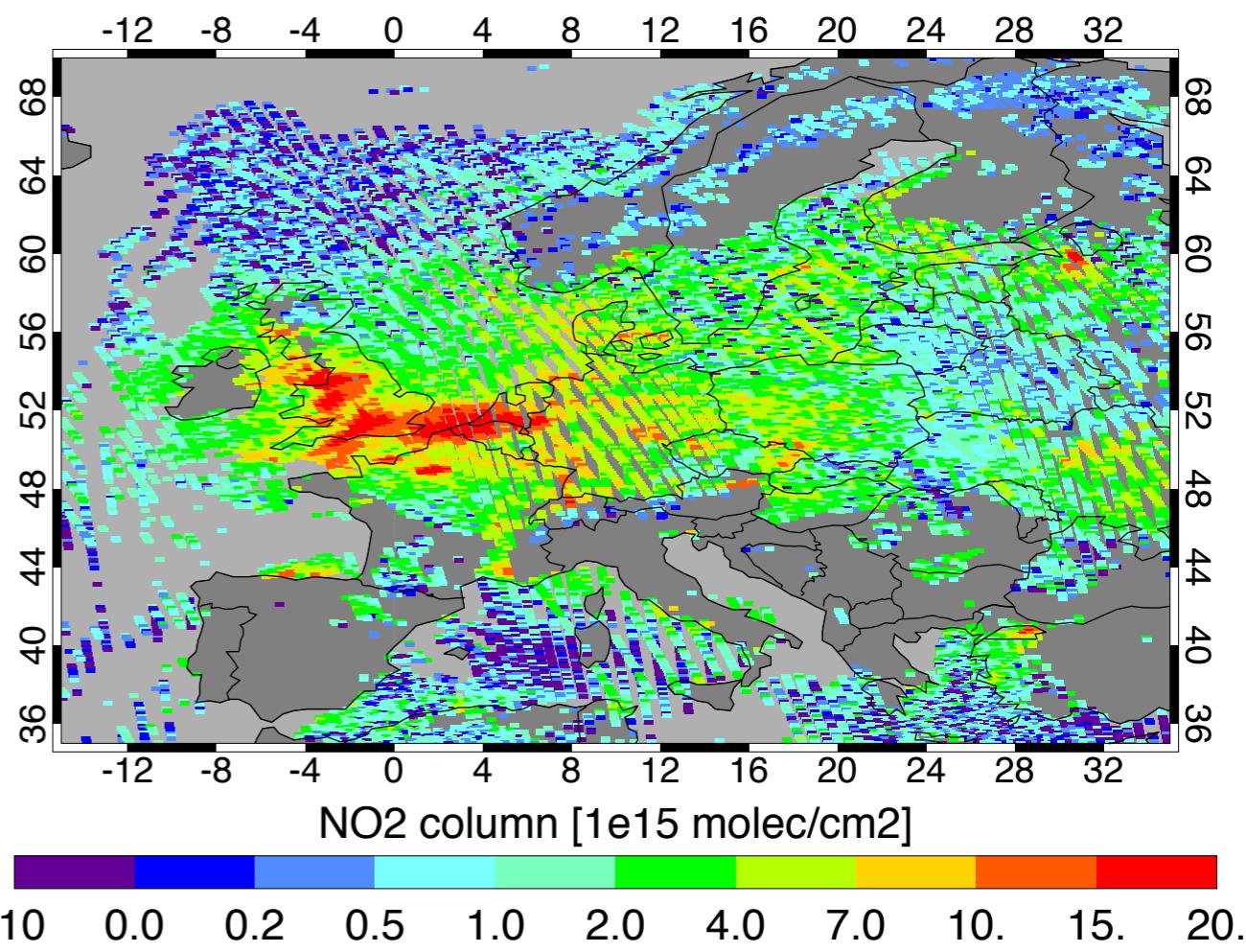
Free model, LE v1.6



OMI NO₂



[NO₂ column] OMI, omi010, 20070326

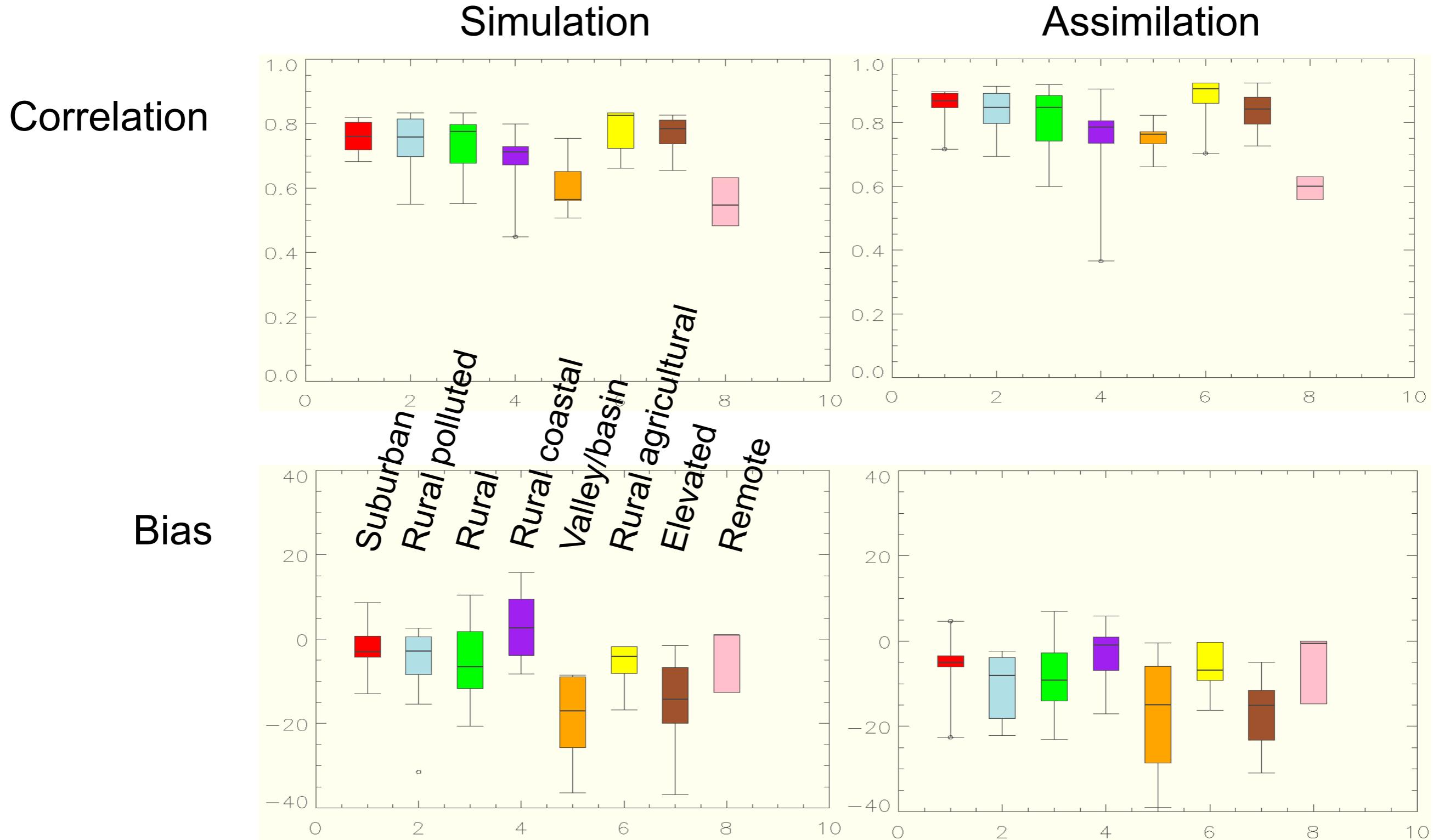


Analysis

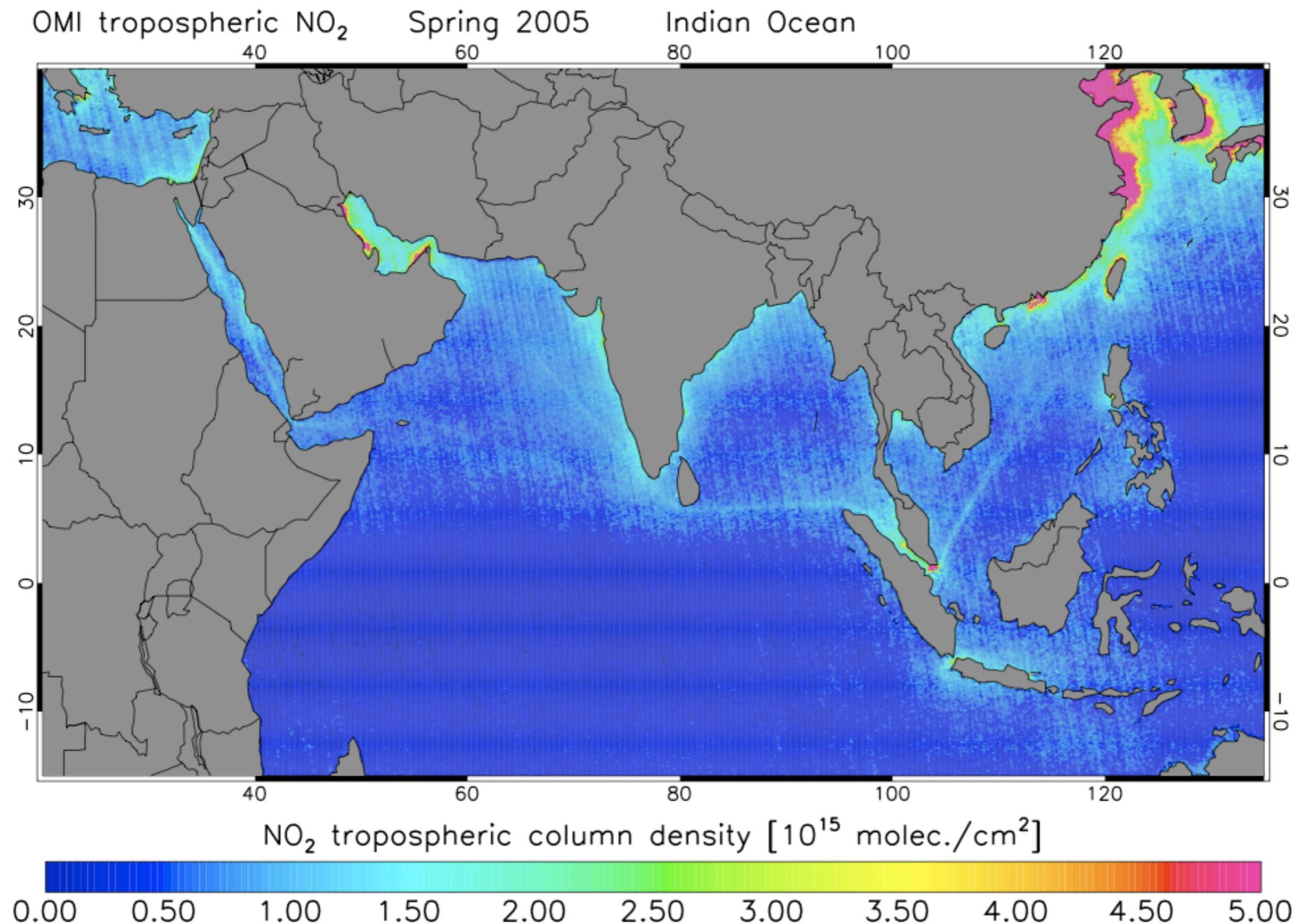




Ozone assimilation - results

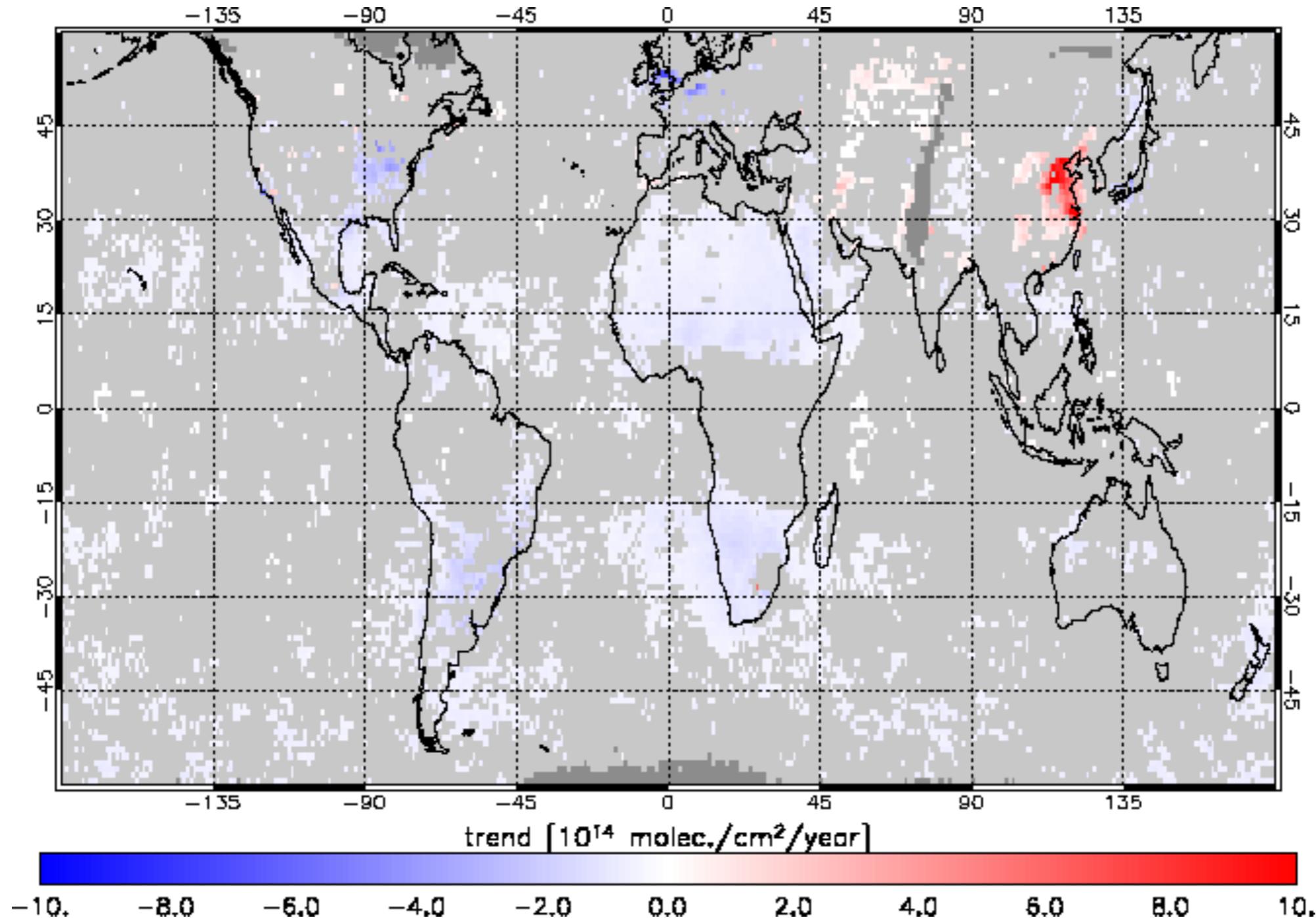


OMI measurements over the Oceans, Asia, Spring 2005





Trend in NO₂ from GOME and SCIAMACHY



Month of maximum NO₂ concentration

month of maximum NO₂ concentration 1996 – 2005 KNMI/IASB/ESA

